Monitoring Procedures for the Assessment of Daylighting Performance of Buildings

A Report of

IEA SHC TASK 21 / ECBCS ANNEX 29

February 2001

INTERNATIONAL ENERGY AGENCY

Solar Heating & Cooling Programme

INTERNATIONAL ENERGY AGENCY

Energy Conservation in Buildings

and Community Systems Programme

Monitoring Procedures for the Assessment of Daylighting Performance of Buildings

by

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Preface

IEA Solar Heating and Cooling Programme

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Organisation for Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 25 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centres.

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its 21 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

Australia	Finland	Norway
Austria	France	Portugal
Belgium	Italy	Spain
Canada	Japan	Sweden
Denmark	Mexico	Switzerland
European Commission	Netherlands	United Kingdom
Germany	New Zealand	United States

A total of 29 Tasks have been initiated, 20 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities--working groups, conferences and workshops--have been organised.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Co-ordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modelling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*

Completed Working Groups:

CSHPSS
ISOLDE
Materials in Solar Thermal Collectors

Current Tasks:

Task 22	*Building Energy Analysis Tools*
Task 23	*Optimisation of Solar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 27	*Performance of Solar Façade Components*
Task 28	*Solar Sustainable Housing*
Task 29	*Solar Crop Drying*
Task 30	*Solar City (Task Definition Phase)*
Task 31	*Daylighting Buildings in the 21st Century (Task Definition Phase)*

Current Working Groups:

Evaluation of Task 13 Houses
PV/Thermal Systems (Definition Phase)
Solar Gain

To receive a publications catalogue or learn more about the IEA Solar Heating and Cooling Programme visit our Internet site at **http://www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, Morse Associates Inc., 1808 Corcoran Street, NW, Washington, DC 20009, USA, Tel: +1/202/483-2393, Fax: +1/202/265-2248, E-mail: pmurphy@MorseAssociatesInc.com.

Energy Conservation in Buildings and Community Systems (ECBCS)

Within the programme of Energy Conservation in Buildings and Community Systems the IEA is carrying out various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. The twenty-one members of the programme are:

Australia	Germany	Poland
Belgium	Greece	Portugal
Canada	Israel	Sweden
Denmark	Japan	Switzerland
European Commission	Netherlands	Turkey
Finland	New Zealand	United Kingdom
France	Norway	United States

A total of 35 projects, called Annexes have been initiated, 26 of which have been completed. In the list below completed projects are identified by *:

Annex 1 *Load Energy Determination of Buildings* *
Annex 2 *Ekistics and Advanced Community Energy Systems* *
Annex 3 *Energy Conservation in Residential Buildings* *
Annex 4 *Glasgow Commercial Building Monitoring* *
Annex 5 *Air Infiltration and Ventilation Centre*
Annex 6 *Energy Systems and Design of Communities* *
Annex 7 *Local Government Energy Planning* *
Annex 8 *Inhabitant Behaviour with Regard to Ventilation* *
Annex 9 *Minimum Ventilation Rates* *
Annex 10 *Building HVAC Systems Simulation* *
Annex 11 *Energy Auditing* *
Annex 12 *Windows and Fenestration* *
Annex 13 *Energy Management in Hospitals* *
Annex 14 *Condensation* *
Annex 15 *Energy Efficiency in Schools* *
Annex 16 *BEMS - 1: Energy Management Procedures* *
Annex 17 *BEMS - 2: Evaluation and Emulation Techniques* *
Annex 18 *Demand Controlled Ventilating Systems* *
Annex 19 *Low Slope Roof Systems* *
Annex 20 *Air Flow Patterns within Buildings* *
Annex 21 *Thermal Modelling* *
Annex 22 *Energy Efficient Communities* *
Annex 23 *Multi-zone Air Flow Modelling (COMIS)* *
Annex 24 *Heat Air and Moisture Transfer in Envelopes* *
Annex 25 *Real Time HEVAC Simulation* *
Annex 26 *Energy Efficient Ventilation of Large Enclosures* *
Annex 27 *Evaluation and Demonstration of Domestic Ventilation Systems*

Annex 28 *Low Energy Cooling Systems **
Annex 29 *Daylight in Buildings **
Annex 30 *Bringing Simulation to Application*
Annex 31 *Energy Related Environmental Impact of Buildings*
Annex 32 *Integral Building Envelope Performance Assessment*
Annex 33 *Advanced Local Energy Planning*
Annex 34 *Computer-aided Evaluation of HVAC System Performance*
Annex 35 *Design of Energy Efficient Hybrid Ventilation (HYBVENT)*

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Contents

1. Introduction

Today, standard monitoring procedures to assess and compare the performance of daylighting systems and daylight responsive artificial lighting control systems are not available. This aspect has now been rectified by the present document, which presents the monitoring methods and performance assessments used in the IEA SHC Task 21 ‘Daylight in Buildings’ work program. The monitoring of daylighting systems and daylight responsive artificial lighting control systems within the IEA SHC Task 21 was carried out in Australia, Austria, Denmark, Finland, France, England, Germany, Italy, the Netherlands, Norway, Switzerland and the USA according to a monitoring protocol. The monitoring of daylighting systems is documented in the *Source Book* (Ruck et al. 2000) and the monitoring of control systems is documented in the *Application Guide* (Zonneveldt et al. 2000).

1.1 Objective

The purpose of the monitoring protocol is to establish a basis for the evaluation of daylighting systems and daylight responsive artificial lighting control systems on a comparative basis in unoccupied or occupied (test) rooms under real sky conditions. This document is a guide, which includes recommendations for different levels of monitoring and evaluation procedures. It specifies the documentation needed for the testing and the evaluation of the systems’ performance as compared to a reference situation.

1.2 Approach

Since a traditional window will often provide a non-uniform daylight distribution, daylighting systems are designed and incorporated in a room in order to achieve a more uniform light distribution. Daylighting systems are checked on their ability to reduce the luminance differences within the room and to control daylight levels and direct sunlight in the perimeter zones for overcast and clear sky conditions. Daylight responsive artificial lighting control systems are checked on their ability to control artificial lighting in response to the available daylight and to decrease energy consumption.

The overall performance of a daylighting system or an artificial lighting control system is determined by the capability of these systems to fulfil the expectations mentioned above while maintaining visual quality (i.e. visual comfort and user acceptance).

1.3 Basic assumptions

Monitoring in *Test Rooms* will establish the performance of daylighting systems and daylight responsive artificial lighting control systems. The rooms are assumed to be standard offices with vertical window(s) and horizontal work planes only.

The performance of a daylighting system or a lighting control system is assessed under similar sky conditions by comparison with an identical *Reference Room,* which does not incorporate the analysed system(s).

- In the monitoring of a daylighting system, for overcast sky conditions, the reference room is considered to be equipped with typical double pane clear glazing. For clear sky conditions, a typical national shading system such as a downward tilted (e.g. 45°) venetian blind covering the complete window (figure 1) is included in the reference room. The measurement procedure in the reference room is similar to the one used in the test room. No artificial lighting system is installed in either room.

- In the monitoring of a daylight responsive artificial lighting control system, the reference room is equipped with luminaires, but no lighting control system or daylighting system are installed.

  The illuminance levels required from the daylight responsive lighting control system to maintain a certain design (target) illuminance in the space will depend on the size and transmittance of the glazing. If the windows are large, and depending on the sky condition, only a low illuminance from the artificial lighting may be required during the day. Therefore, in order to be able to see the actual performance of the control system and use its entire dimming range, the design illuminance has to be set higher. If the windows are small and the glazing transmittance is low, the artificial lighting will need to provide a higher level of illuminance and the design illuminance can be set lower.

  A lighting control system can be adjusted to provide the optimum design illuminance. In this way the over installed power is saved. These savings, however, are not due to the daylight responsiveness of the control system. This is an advantage of a control system, but it does not reveal how well the system controls the artificial lighting in response to the available daylight. In order to monitor the lighting control system only, the room design illuminance should equal the 0% dimmed status of the artificial lighting (100% output).

It is difficult to estimate the hours-of-use of a system when it is manually controlled, since this depends on arbitrary factors such as occupancy patterns and user behaviour. Therefore the effects from manual switching are excluded. The luminaires in the reference situation have a 100% output (0% dimmed status) during the whole testing period (figure 1). If the dimming level of the artificial lighting is monitored, the illuminance distribution for the reference situation can be calculated and no additional room is needed for this purpose (see chapter 5).

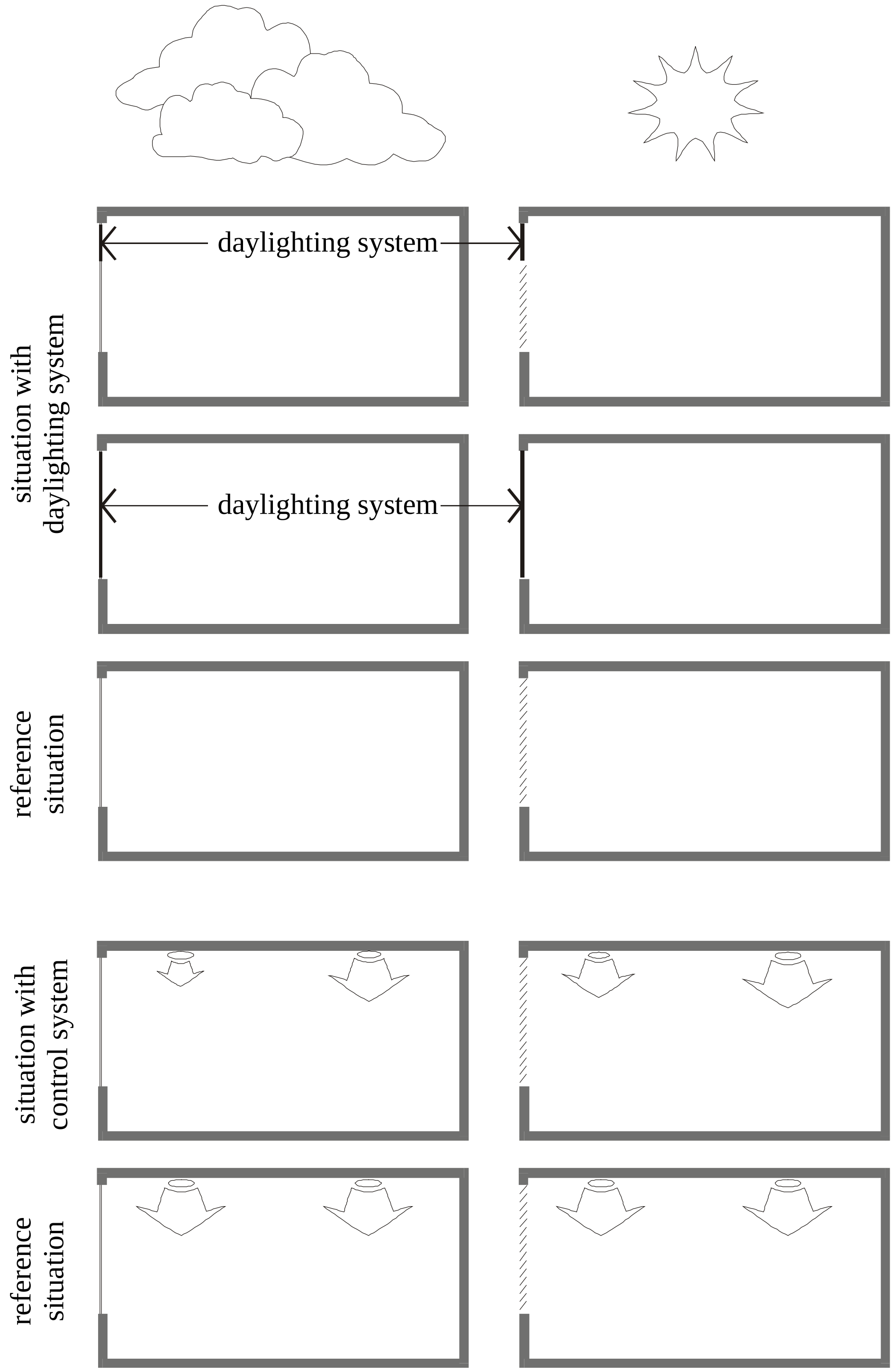


Figure 1 Basic assumption with respect to the Reference Situation

1.4 Outline of this document

The complete monitoring procedure consists of four phases as shown in figure 2, which will determine the structure of this document.

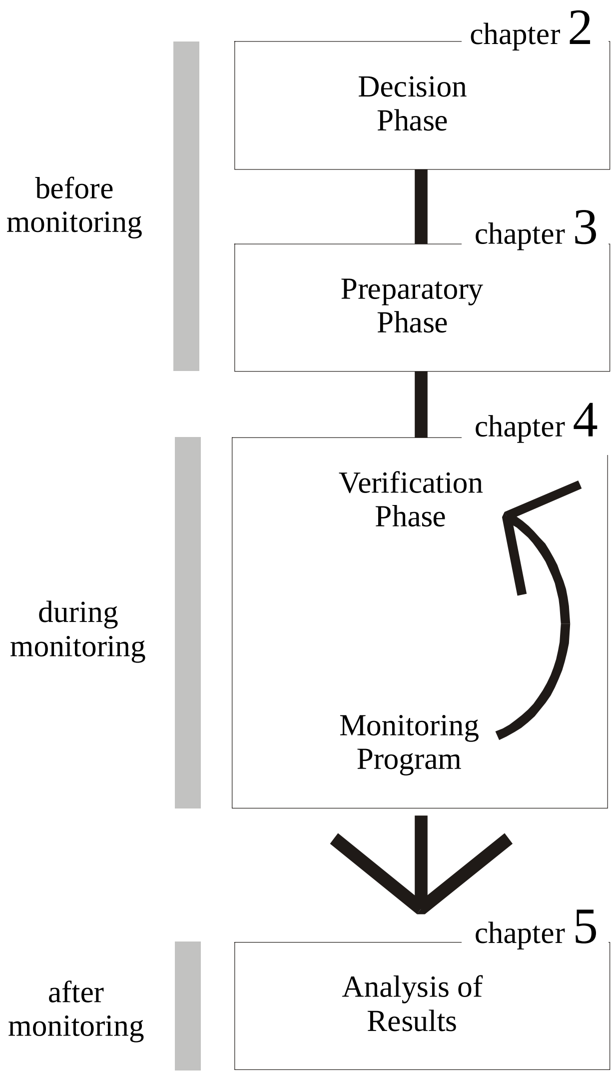


Figure 2 Schematic of the document structure

1) The *decision phase*, in which decisions are made about the testing and the type of measurements to be carried out. A checklist with possible monitoring aspects and required measurements is given in Chapter 2 'The decision phase'.
2) The *preparatory phase*, in which a descriptive document containing information on the monitoring equipment and the test conditions is provided. An example of a descriptive document is included in Chapter 3 'Descriptive document'.
3) The *monitoring program* in which the daylighting systems and the daylight responsive artificial lighting control systems are tested. The program can include long-term or short-term measurements, and a verification phase in which the test conditions and sensors are systematically checked (see Chapter 4 'Monitoring Program').
4) The *concluding phase*, in which the performance of the daylighting systems or the daylight responsive artificial lighting control system are analysed based on the monitoring results.

2. The decision phase

Before commencing the monitoring of a daylighting system or a daylight responsive artificial lighting control system, the aspects that need to be tested should be determined.

2.1 Determination of required measurements

Tables 1 and 2 provide guidelines on how to evaluate the performance of an applied daylighting system and a daylight responsive artificial lighting control system. The tables are checklists that help to determine the required measurements. In chapter 5 an evaluation of the measured quantities is given. It is advisable to look at this analysis before commencing the monitoring so that no evaluation measure is missed.

2.2 Information on required measurements

This section provides recommendations related to the monitoring equipment, the number of sensors, and the time and frequency of the monitoring. For more detailed information about exterior measurements and instrumentation requirements, guidelines and recommendations on data quality control, archiving and dissemination, consult the CIE published *Guide to recommended practice of daylight measurements* (CIE 1994).

Exterior measurements

When conducting exterior measurements the following should be kept in mind:

- Sensors should be V_λ corrected and cosine-corrected by rotation symmetry and only be dependent on the angle of incidence and independent of the azimuth angle.
- Sensors should have a linear response with increasing illuminance
- Sensors should be accurate in the illuminance range 0 – 100,000 lux up to 150,000 lux, depending on the daylight availability at the location where the monitoring takes place

It is also preferable that the exterior illuminance sensors are waterproof and able to maintain a stable temperature to prevent condensation and ice coating (see also CIE 1994).

Table 1: Required measurements for the monitoring of a daylighting system

Aspect	**Required information source**
Minimum monitoring	
Realise a higher illuminance level on the work plane	❑ Horizontal illuminance on the work plane (E_{wp} in the middle of the room, e.g. $E_{wp\ 1-5}$ in figure 4) ❑ Horizontal global illuminance (E_{vg}) ❑ Vertical sky illuminance on the façade (E_{vgs})
Improve daylight distribution	❑ Horizontal illuminance on the work plane (E_{wp} in the middle of the room, e.g. $E_{wp\ 1-5}$ in figure 4) ❑ Horizontal global illuminance (E_{vg}) ❑ Vertical sky illuminance on the façade (E_{vgs})
Additional monitoring	
Daylight distribution	❑ Horizontal illuminance on the work plane (E_{wp}, on the whole work plane, e.g. $E_{wp\ 1-15}$ in figure 4)
Change in daylight distribution	❑ Horizontal illuminance on the work plane (E_{wp} in figure 4) ❑ Vertical illuminance on the walls (E_{Wall}, e.g. $E_{Wall\ 1-4}$ in figure 4) ❑ Illuminance on the ceiling ($E_{Ceil.}$) ❑ Luminance of the wall, L_{wall} ❑ Luminance of the ceiling, L_{Ceil}
Detection of sun patches, areas of high luminances, glare and colour dispersion	❑ Observation ❑ Photographs that register the lighting conditions
Maintain user acceptance	❑ User evaluation ❑ Photographs that register the lighting conditions

Exterior global illuminance on a horizontal plane, E_{vg}

Exterior sky measurements can be carried out with one exterior sensor, mounted on a horizontal plane with an unobstructed horizon (e.g. roof), to measure horizontal global illuminance. If there are significant external obstructions, the measurements should be corrected according to the recommendations proposed in Appendix A. This correction is only applicable to CIE overcast sky conditions and no such correction can be proposed for clear sky conditions yet.

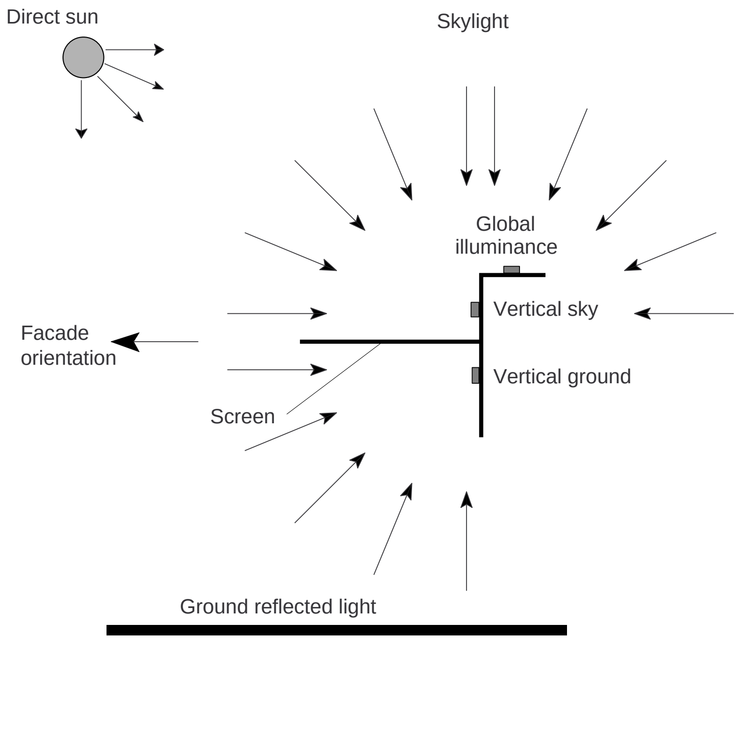
Exterior illuminance on a vertical plane, E_{vgs}

Exterior vertical illuminance E_{vgs} should be measured with the help of a sensor screened from ground-reflected light by a matt black screen (see figure 3, vertical sky).

An additional sensor might be needed in situations where the ground reflection may change significantly (for example, due to snow on the ground) and a distinction between the contribution of the ground and the prevailing sky condition needs to be made. If the sensor is unscreened, the ground reflected component can be found by subtracting the unscreened vertical sky and ground component from the screened sensor measuring the vertical sky illuminance. The ground component can also be measured directly with a screened sensor (see figure 3, vertical ground).

Table 2: Required measurements for the monitoring of a daylight responsive artificial lighting control system

Aspect	**Required information source**
Minimum monitoring	
Maintain the design illuminance (E_{set})	❑ Illuminance on the work plane (minimum E_{wp} on the work plane, e.g. $E_{wp\ 1\text{-}3}$ or $E_{wp\ 1\text{-}9}$ in figure 5)
Decrease electrical energy consumption for artificial lighting	❑ Power consumption ❑ Time of use Or ❑ Dimming level (voltage) ❑ Power consumption (a preparatory measurement)
Additional monitoring	
Maintain user acceptance	❑ User evaluation ❑ Photographs that register the lighting conditions



Interior measurements

Horizontal illuminance on the work plane (E_{wp})

The quantity and distribution of the horizontal illuminance can be monitored by a number of sensors. The actual number will depend on several aspects, such as the availability of sensors, the system to be tested, the size of the window opening and the required information (results). A suggestion regarding the position of the sensors for a daylighting system and a daylight responsive artificial lighting control system is given in figures 4 and 5, respectively. The minimum sensors for monitoring are sensors 1 to 5 for a daylighting system, and sensors 1 to 3 for a control system. The sensor height will be according to the standard work plane height of each specific country. If no standard exists, the measuring height can be 0.8 m.

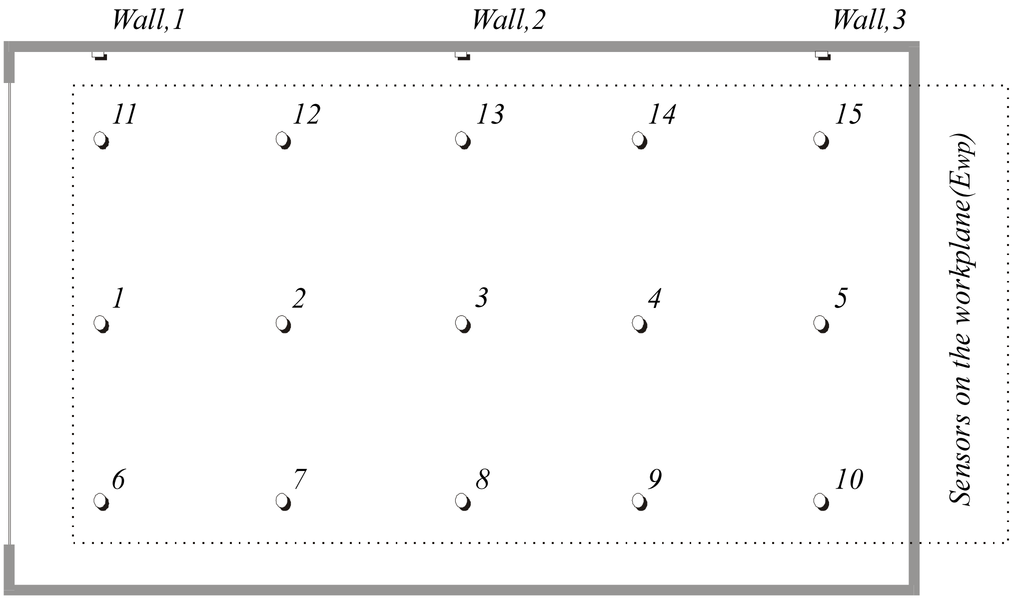


Figure 4 Possible positions of sensors – Daylighting system (see also Appendix B)

Vertical and horizontal illuminances on the side wall and ceiling (E_{wall} and E_{ceil})

Illuminance measurements can be used to describe the daylight and sunlight distribution on the work plane and on the walls. The vertical illuminance measurements on the walls can be measured at 1.2 and / or 1.8 m above floor level, the seated and the standing positions at eye level. A proposal for the sensor position is given in figure 4.

For daylighting systems that redirect the light towards the ceiling, additional measurements on the ceiling can be taken. The actual position of the sensors will depend on the type of daylighting system and can be determined after the installation of the system. The position of these sensors can be according to the minimum number of sensors on the horizontal plane given in Appendix B.

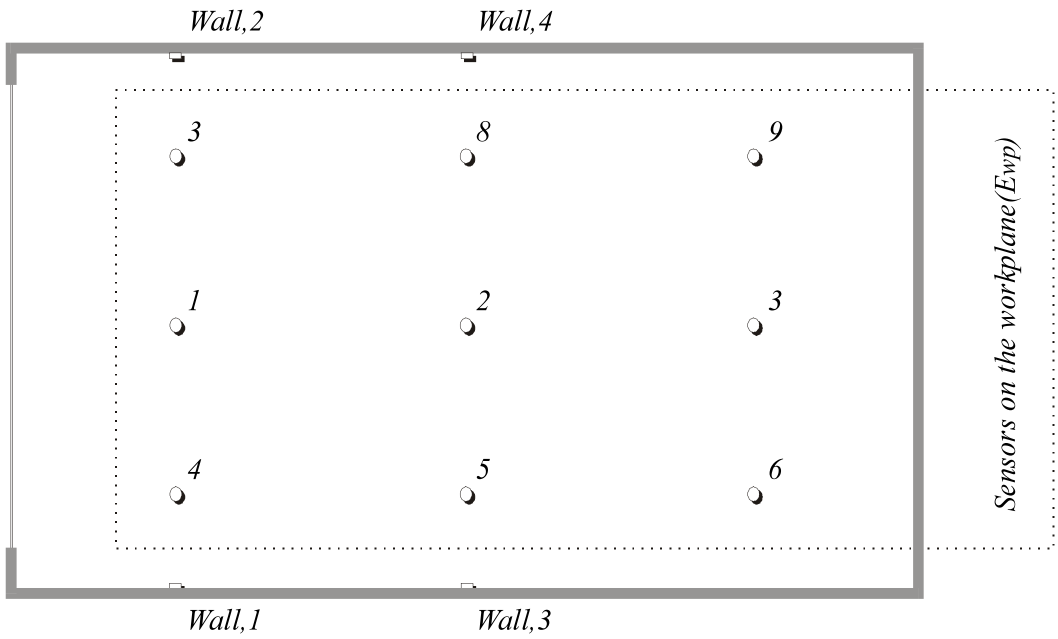


Figure 5 Possible positions of sensors – Daylight responsive artificial lighting control system (see also Appendix B)

Luminance of walls and ceiling (L_{wall} and L_{ceil})

A luminance meter can be used to spot measure the luminance on the ceiling and the side walls in order to estimate the luminance ratios within the room. Luminance values on the side walls should be taken at eye-level, both seated and in a standing position (1.2 and 1.8 m from the floor). Divide the room into three equal parts and take measurements in the centre of each part at the specified height level above the floor. Make sure that the exterior light levels are fairly stable during the spot measurements. These readings should be taken for both completely overcast and clear sky conditions. Especially for systems that rely on the sun position for their daylight performance, these spot measurements should be taken at least three times a day (morning, noon and afternoon hours). Luminance values on the ceiling should be taken in the same position and at the same distance from the window as described for spot measurements on the side wall.

Power consumption

Using a standard energy meter (kWh) meter, the electric energy consumption during the test period (W_{total}) can be determined. With a power meter, the power consumption (P_i) measured within a certain time interval (Δt) can also be determined. A summation for the entire test period leads to the overall electrical energy consumption.

Dimming level

The dimming level (δ) is a measure of the fractional light output, assumed to run between 0 and 1. In a preparatory measurement, the relation between the measured voltage (a measure for the dimming level of the artificial light) and the power consumption can be determined, using a voltmeter and a power meter (see figure 6). With the established relationship, the dimming level can be used to monitor the energy consumption.

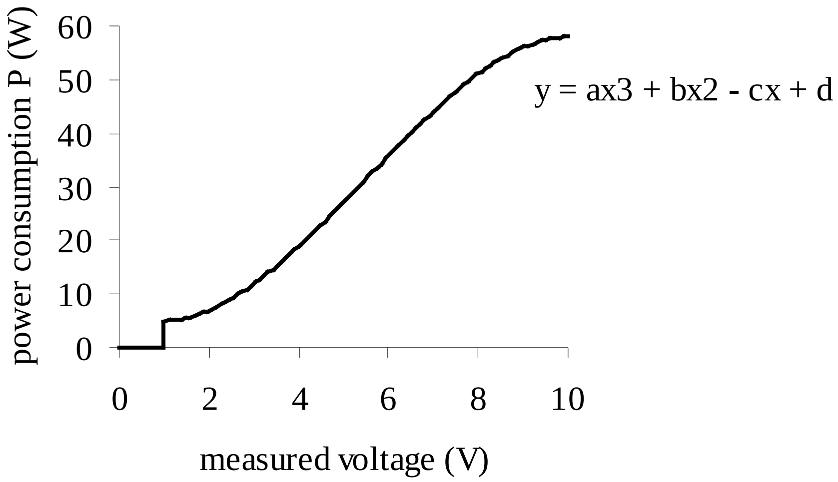


Figure 6: ***Example of relation between measured voltage and the power consumption of the artificial lighting***

2.3 Collection of information through observation

Monitoring through observation can take place in unoccupied as well as occupied test rooms. In the occupied test rooms, the subject in the (test) room can make these observations throughout the day. In the unoccupied test rooms, it is recommended that the responsible expert be present in the test rooms (and the reference room) during a significant part of the testing period, because of the very dynamic behaviour of daylight, especially under clear sky conditions.

This will additionally save time in the analysis of the recorded data, when decisions have to be made about whether data are valid, and which data have to be excluded.

It is preferable to take photographs during the observations, so that the evaluated lighting condition is registered. Information on luminance values and luminance distributions can be recorded on these photographs as well, when the luminance measurements are not conducted with a CCD camera (see figures 7 and 8).

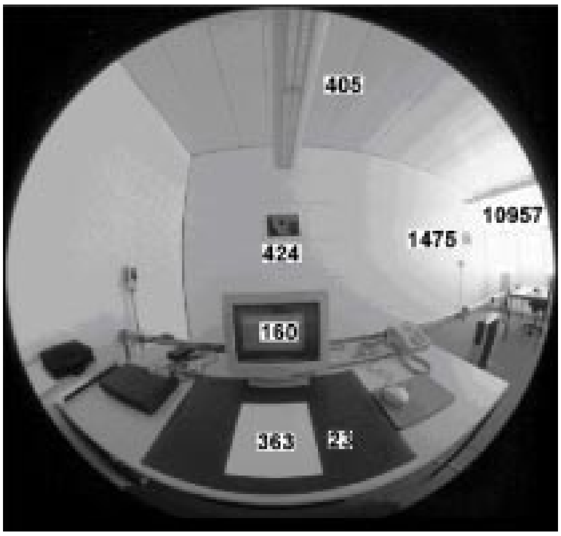


Figure 7: Luminance values within the field of view pointed towards a desk, measured with a luminance meter and recorded on a fish-eye picture

Figure 8: Luminance values (in cd/m²), in a room with laser-cut panels at 10 (true solar time), measured with a CCD camera

The responsible expert or the subject in the test room should make the following observations throughout the day:

Detection of sun patches

A detection of time periods when undesirable sun patches are present in the room should be made. The information should be reported through photographs or time lapse video.

Detection of areas with high luminance

The recording of high luminance areas in the test room and reference room should be made. Luminance measurements and luminance ratios need to be recorded for both overcast and clear sky conditions. The evaluations should be made throughout the day at least three times a year (summer and winter solstices, equinox).

Detection of glare

A detection of time periods when direct or indirect glare due to the sun or due to areas with a high luminance (windows) is experienced should be made. The luminance values and luminance ratios should be recorded. This evaluation needs to be carried out at least three times a year (summer and winter solstices, equinox).

An experimental set-up has been proposed by Aizlewood, to assess the potential discomfort glare from the window. This is described in Appendix C.

Detection of colour dispersion

Depending on the daylighting system tested, a detection of the time periods when undesirable colour dispersion is present in the interior should be made. Information should be reported through photographs. This evaluation can be done at least three times a year (summer and winter solstices, equinox).

2.4 Collection of information through user assessments

In the occupied test rooms, the assessment of the users' opinions about the installed daylighting systems will complement the measurements of the room's physical conditions. Most daylighting systems and control systems will normally be more technological and more expensive than traditional windows. However, the choice for such a system can be made if it improves the comfort or the working conditions from the users' viewpoint when compared to the more traditional solution.

The procedures and questionnaires developed for the assessment of the users' opinions has not been tested thoroughly within IEA Task 21. The procedure and the questionnaire for evaluating situations with daylighting systems is given in Appendix E. The questionnaire is designed for small office rooms for 1 – 3 persons, with window(s) on at least one façade and furnished in such a way that the subjects will get a feeling of being in a normal, functioning office. No procedure was developed for situations with lighting control systems. In general, this procedure should outline the questionnaire used to obtain the subjects' impression, opinion and experience of the room and the installed lighting control system during their one-hour stay in the test room, while performing certain office-like tasks.

3. Descriptive document

Once the required measurements are determined they need to be depicted in a descriptive document together with the test conditions. It is important to put the results in the perspective of the test conditions, since they influence the system's performance significantly. In the descriptive document all the information related to the conditions that will remain unchanged during the monitoring program need to be recorded, including information on the test rooms, the monitoring equipment and the monitoring procedures. These three aspects will be discussed in this chapter, which concludes with an example of a descriptive document.

3.1 Description of the test room

The description of the test rooms with daylighting systems or control systems should include the following information :

- Number of test rooms
- Orientation
- Internal length, width and height
- Window and glazing area
- Material photometric properties (support for measurement of these properties can be found in appendix F and G)
- Luminaire description (manufacture, lamp, ballast, control system)
- Daylight system description
- Monitoring (Measuring) equipment

This description could also include information on the problems encountered during the installation of the daylighting and lighting control systems.

3.2 Description of the monitoring equipment

The description of the monitoring equipment should include information on:

- Position of interior sensors
- Monitoring equipment (date of calibration, calibration error, $V(\lambda)$ match error, cosine response error, fatigue error)
- Data acquisition system (manufacturer, type, data acquisition software)

The estimated overall accuracy of the measurements should be given, and this is mostly based on the information provided by the manufacturers of the monitoring and data acquisition equipment.

3.3 Description of the monitoring procedures

The description of the monitoring procedures should show the duration and level of the monitoring used.

3.4 Example of a descriptive document

This paragraph shows an example of a descriptive document, which contains the information that should be registered before any experiment is conducted:

<u>IEA TASK 21 - Subtask A and B - Descriptive document on test rooms</u>

1) Person responsible for the monitoring

Name	:	*Mr. X*
Organisation	:	*Institute for Electronics and Lighting Technology* *Einsteinufer 19, Berlin, Germany*
Phone	:	*314.00000*
Fax	:	*314.00000*
E-mail	:	*Mr.X@ee.tu-berlin.de*

2) General information on test room

City	:	*Berlin*
Country:	:	*Germany*
Elevation	:	*51 m*
Longitude	:	*13° 18′ E*
Latitude	:	*52° 28′ N*
Number of test rooms	:	*3*
Construction date	:	*1988*
Orientation of test rooms	:	*183° (N=0°, E=90°, S=180° and W=270°)*
Internal length	:	*4.70 m (7.10 m)*
Internal width	:	*3.50 m*
Internal height	:	*3.00 m*
Window area	:	*7.00 m²*
Glazed area	:	*4.75 m²*
Are the rooms occupied?		✔ yes ✔ no *the test rooms were occupied during the monitoring period between September 1998 and February 1999; during the other monitoring periods the rooms were unoccupied*

Occupancy pattern : *5 days a week, from 9.00 to 18.00*
Occupants' activities : ❒ Mostly VDT tasks
❒ Mostly paper-based tasks
✔ VDT & paper-based tasks
❒ Other (specify) : _______________

Are the rooms air conditioned ?:❒ yes ✔ no

3) Pictures

#1 *Outdoor, facing the test room, and showing the building's façade*
#2 *Through the room's windows, showing the outside view and the external obstructions*
#3 *Indoor, from the back of the room, toward the front of the room*
#4 *Indoor, from the front of the room, toward the back of the room*

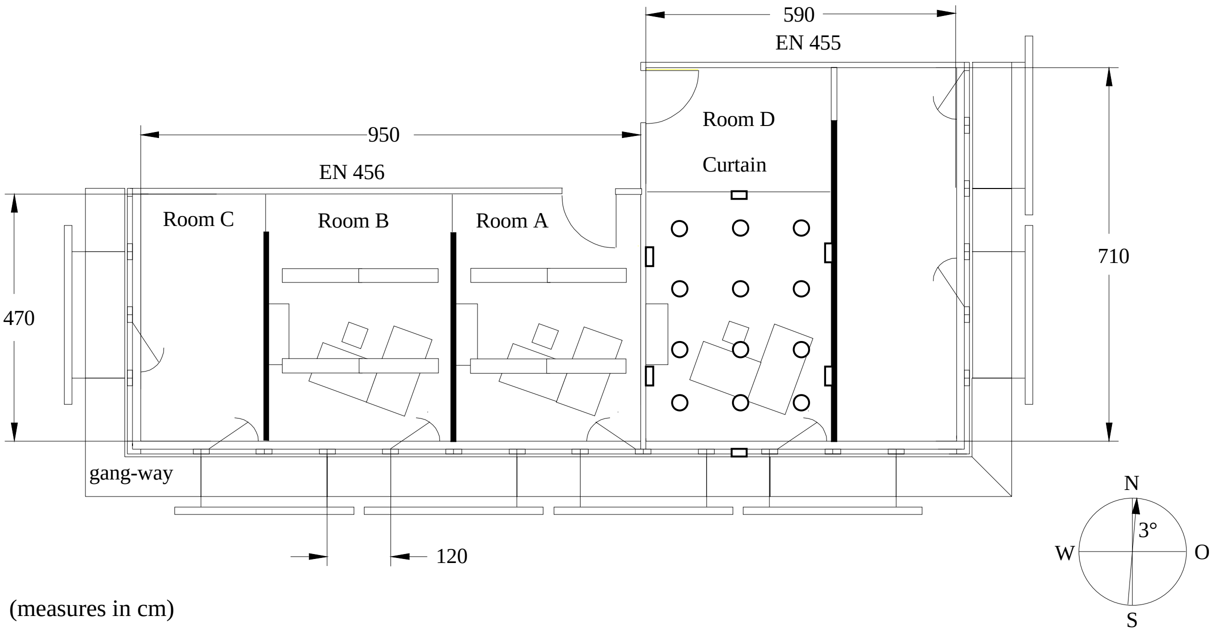

1


2


3


4

4) Plans & Elevation



(measures in cm)

5) Material photometric properties

Opaque surfaces

		ρ_{dif}(%)	Mat or Glossy ?	Colour
Walls	:	*70*	*Mat*	*White*
Floor	:	*20*	*Mat*	*Grey*
Ceiling	:	*80*	*Mat*	*White*
Desk	:	*60*	*Mat*	*Grey*

Transparent or translucent surfaces

		τ_{dif}(%)	$\tau_{\perp}$(%)	Material	Colour	u[W/(K.m^2)]	g(%)
Glazing	:	*70*	*80*	*double float glass 6 mm*	*white*	*1.7*	*75*

Shading device : *simple blinds (grey, Hüppe Form Sonnenschutzsysteme)*

6) Luminaire Description

General information

		Room A Luminaire Type #1	*Room B Luminaire Type #2*	*Room D Luminaire Type #3*
No. of lamps/luminaire:		*2*	*2*	*2*
Luminaire size (W x L x H):		*1530x265x69*	*1556x270x100 mm*	-
Type:	Ceiling mounted (or recessed)	✔	✔	✔
	Suspended	❐	❐	❐
	Wall mounted	❐	❐	❐
	Floor lamp	❐	❐	❐
	Desk lamp	❐	❐	❐
Type:	Direct	✔	✔	✔
	Indirect	❐	❐	❐
	Direct/Indirect	❐	❐	❐

Optics

Manufacturer:		*Siemens*	*Zumtobel*	*Philips*
Direct Efficiency (%):		*52*	*56*	-
Indirect Efficiency (%):		-	*3*	-
Optic type:	Prismatic lens	❐	❐	❐
	Diffuser lens	❐	❐	❐
	Flat-bladed louvers	❐	❐	❐
	Parabolic louvers	❐	❐	❐
	Asymmetric	❐	❐	❐
	Non optic	❐	❐	❐
	Other (specify)			

Lamp

Manufacturer:		*Osram*	*Osram*	*Osram*
Position:	Horizontal	✔	✔	✔
	Vertical	❐	❐	❐
Type:	Full-size fluorescent	✔	✔	✔
	Compact fluorescent	❐	❐	❐
	Other (specify)			

Unit power (in Watts):	*58*	*58*	*58*
Lamp flux (in Lumens):	*3300*	*3300*	*3300*
Colour temperature (in Kelvin):	*3850*	*3850*	*3850*
Colour Rendering Index:	*95*	*95*	*95*

Ballast

Manufacturer:		*Siemens*	*Zumtobel*	*Philips*
Type:	Electromagnetic	❒	❒	❒
	Electronic	❒	❒	❒
	Dimmable	✔	✔	✔

7) Daylighting systems

Tested daylighting systems:

Specular refl. louvres	❒ __	Diffusing refl. louvres	✔__
Roller blinds, screens, films	❒ __	Light shelves	❒ __
Refractive panels	❒ __	Sundirecting clerestory (LWT)	❒ __
Prismatic panels, -shading, -directing	❒ __	Prismatic films	❒ __
Lasercut panel	❒ __	Holographic systems	❒ __
Ed-shades	❒ __	Anadolic systems	❒ __
Shaded skylight	❒ __	Sundirecting skylight	❒ __
Angle selective coating	❒ __	Sloping ceiling (room geometry)	❒ __
Light pipes (glass fibres)	❒ __	Light pipes (close to window)	❒ __
Other: _______________	❒ __		

Can the systems automatically be controlled? *Yes*

8) Internal Measurements

The position of the sensors is given in the plan shown above in item 4)

Illuminance: Number of sensors ❒ minimum (7 sensors)
✔ more [*12*] (specify)

Height of sensors ❒ 0.70 m ✔ 0.85 m ❒ other (specify) [___ m]

Luminance:
❒ L-Scanner
✔ CCD-Camera
this CCD camera was calibrated by TechnoTeam in Illmenau, with an accuracy of 10%, close to V(λ) match
❒ L-Meter
❒ Picture + L-Meter

Electrical Energy ✔ *2 Power meters in every test room*

9) External Measurements

The following external measurements were carried out:

✔ Global horizontal illuminance
❒ Diffuse horizontal illuminance
✔ Global horizontal irradiance
❒ Diffuse horizontal irradiance
✔ Illuminance from sunlight and skylight on vertical surfaces facing N, E, S and W
✔ Sunshine duration
❒ Direct (normal) solar illuminance
✔ Direct (normal) solar irradiance
✔ Zenith luminance
✔ Luminance distribution of sky (specify: *with sky scanner and CCD camera)*

10) Measurements under artificial lighting

These measurements were done at 100% dimming level without daylight
E1H: 1000 lx (at 1.50 m)
E2H: 1580 lx (at 3.00 m)
E3H: 1220 lx (at 4.30 m)

4. Monitoring Procedure

The Monitoring Program consists of a verification procedure and the actual monitoring, both described in this chapter.

4.1 Verification procedure

Every monitoring period starts and ends with a verification procedure, which is needed to record changes in the test rooms and in the functioning of the monitoring equipment. The verification procedure consists of:

Preparation of the monitoring:

- Check the signals from all sensors systematically and clean the glazing.
- Before installing a new daylighting system, check whether identical daylighting conditions are realised in the reference room and the test room where the daylighting system will be installed.
- Check the descriptive document about changes in test conditions; points of attention could be movable systems, movable curtains, external obstructions and ground conditions (for example including the reflection of snow). These changes should be recorded in the description of the monitoring (see for example Appendix H 'Description of the monitoring').

Preparation of each monitoring day:

- Exterior sensors should preferably be cleaned every monitoring day.

Conclusion of each monitoring day:

- Record the weather conditions during the monitoring period.

Conclusion of the monitoring:

- Check the signals from all sensors.
- Check the descriptive document regarding changes in the test conditions. These changes should be recorded in the description of the monitoring.

4.2 Points of attention in the monitoring program

The monitoring program consists in the collection of data through measurements and observation. Aspects that are important in this program are as follows:

Duration of monitoring

A minimum evaluation of a daylighting or daylight responsive artificial lighting control system will take one day under overcast sky conditions and three days under clear sky conditions. A distinction can be made between long-term monitoring (2 weeks/season to a year) and short-term monitoring (4 days).

In general, measurements should be taken as fast as possible. An average value of any measured parameter should be stored every 6 minutes (10 measurements per hour) from 9 a.m. to 5 p.m. (or in Scandinavian countries, from 8 a.m. to 4 p.m.). Shorter sampling intervals could also be used. Long term monitoring (2-3 weeks around the winter and summer solstices and the equinox) is recommended especially in the monitoring of daylight responsive artificial lighting control systems, in order to establish realistic energy saving potentials. For moderate climates in which daylight conditions change constantly, one or two weeks of monitoring provide an insufficient monitoring period.

Registration of the weather conditions

In order to be able to extrapolate the results to other times of the year it is necessary to record (at least) manually the weather conditions during the test period (see, for example, table 3). Generally, it will be sufficient to describe the weather conditions such as clear, hazy, overcast, partly overcast with sun, etc. In this way the system's performance can be related to the environmental conditions under which it occurred.

Table 3: Registration of weather conditions during the test period

Date	Weather condition
12 01 99	*overcast*
13 01 99	*clear*
19 01 99	*cloudy*

Definition of the weather conditions

Overcast measurements

The overcast sky conditions, by definition, will most likely provide conditions easy to reproduce, due to the distribution of daylight entering the room almost independent of the solar azimuth angle. The main problem is the variation in the sky luminance distribution under which the measurements are made. To compensate for these variations, the following criterion for accepting the measurements is defined. The luminance ratio (f_{oc}) between the screened vertical sky illuminance and the global, unobstructed horizontal illuminance should be in the interval $0.36 < f_{oc} < 0.44$. The 'true value' for the CIE overcast sky is $f_{oc} = 0.396$.

The overcast sky measurements could be taken at any time of the year. For an overcast sky with an ideal CIE sky luminance distribution only one measurement is needed. However since this ideal distribution is seldom reached in some climatic zones, it is recommended that a full day of measurements is carried out, to reveal discrepancies of the sky luminance distribution.

The daylight measurements for overcast sky conditions should be conducted in a period when the exterior illuminance level is high. This will improve the accuracy of differences in signals from the sensors of the two rooms.

Clear sky measurements

A clear sky can be defined by the rule of observation. At least 7/8 of the sky must be uncovered for the sky to be considered clear, and the covered patch of the sky must not cover the sun or be seen from the interior.

Measurements under a clear sky with direct sun should be conducted during an entire day, at the following times of the year:

- winter solstice (+/- 4 weeks, 1 day)
- equinox, either spring or autumn (+/- 4 weeks, 1 day). In locations where there is a significant discrepancy between the spring and the autumn equinox, it is recommended to measure during both equinox.
- summer solstice (+/- 4 weeks, 1 day)

This means that the complete monitoring program for a daylighting system or a daylight responsive artificial lighting control system will cover at least a six months period (i.e. the winter and summer solstice, spring or autumn equinox) with clear sky conditions.

5. Analysis of results

The analysis of the monitoring results will be based on the comparison between the reference situation and the situation with the analysed systems installed. In this chapter the analysis of the results with both minimum and additional monitoring is described.

5.1 Minimum monitoring of Daylighting Systems

Comparison of illuminance levels for sensors positioned on the work plane

The comparison of illuminance levels on the work plane, as a result of using a daylighting system, can be described using the following indices:

- Under overcast sky conditions: Daylight factors (figure 9) or percentage change in illuminance level between the room with the daylighting system and the reference room with clear glass. The daylight factor can be found by:

$$Daylight\ factor = \frac{E_{wp1-5}}{E_{vg}} \cdot 100$$

  The percentage change should be presented as a function of the solar azimuth and azimuth angle throughout the day (Aizlewood 1993). The relative percentage increase in interior illuminance levels can be found by:

$$Percentage\ increase\ in\ illuminance = \frac{E_{testroom} - E_{referenceroom}}{E_{referenceroom}} \cdot 100$$

- Under clear sky conditions: Absolute illuminance level for a position (E_{wp}) on the work plane (figure 10) or percentage change in illuminance level between the daylight system and the reference room with clear glass and/or shading system.

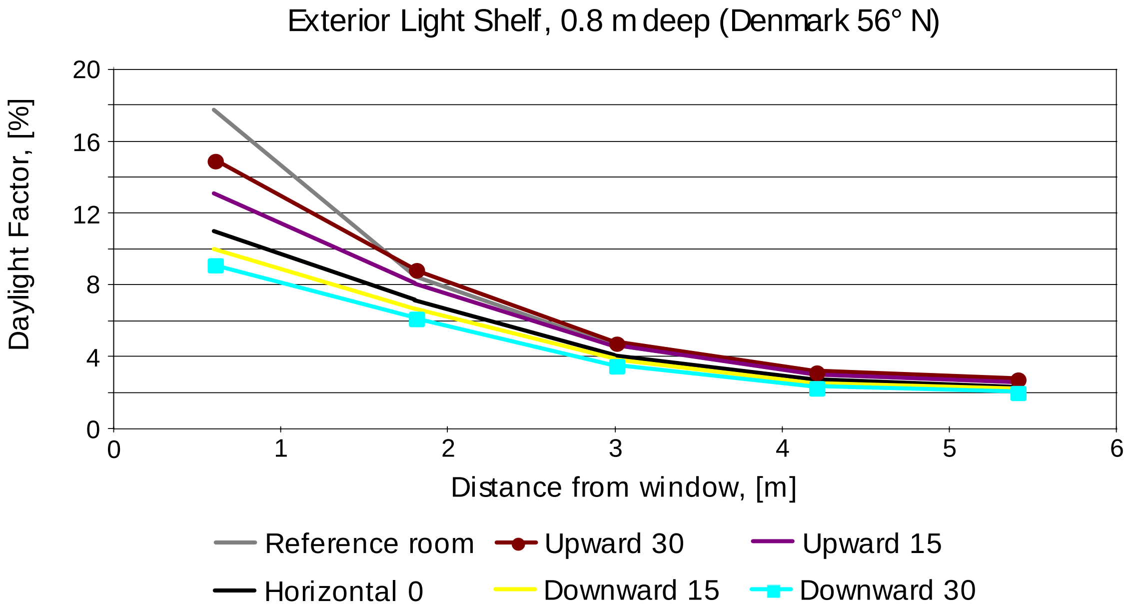


Figure 9 ***Daylight Factors for the reference situation and the test room with a movable light shelf***

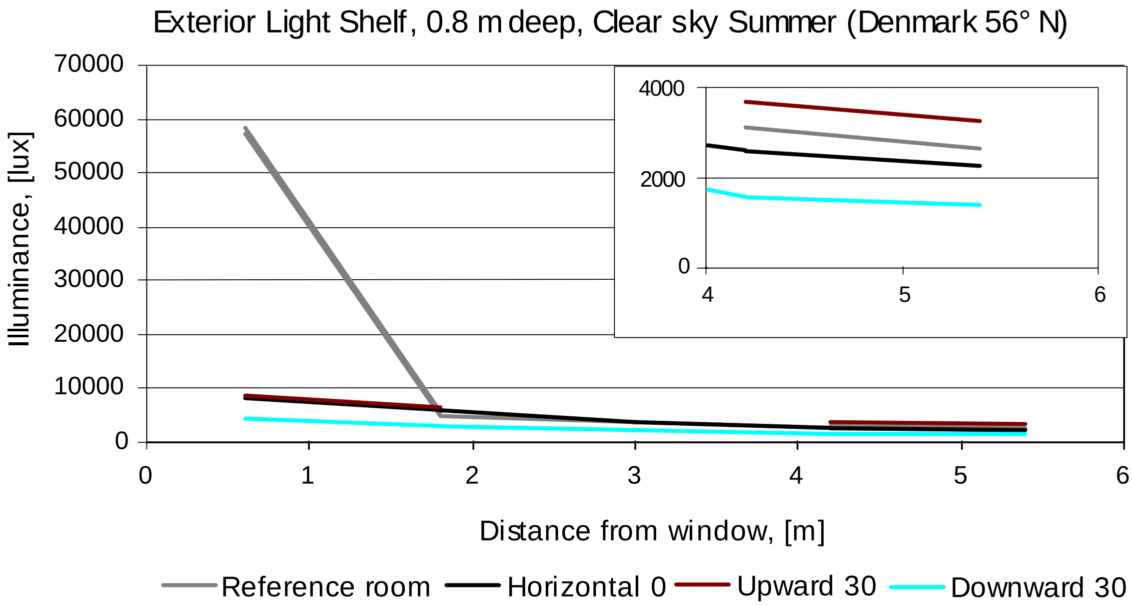


Figure 10 ***Illuminance values for the reference situation and the test room with a movable light shelf***

To improve daylight contribution

Windows in the façade can generate a non-uniform daylight distribution, where the window area can be excessively bright while the back of the room may appear gloomy. A daylighting system can be designed to even out these effects. The improvement can be ascertained by the illuminance on the work plane (E_{wp}), the daylight factor profile, and the horizontal and/or vertical ratios characterising the daylight distribution within the room.

- Under overcast sky conditions: A uniform daylight distribution may cause the interior to loose character and appear dull. The range of daylight factors on the work plane should preferably be within 10:1.
- Under clear sky conditions: The daylighting system should protect against direct sunlight on the work plane (illuminance on the work plane (Ewp). Supplementary shading and/or artificial lighting may not be needed if the targeted illuminance levels from daylighting are maintained on the work plane. However, if the shading system itself or other room surfaces become extremely bright or dark, artificial lighting may be needed to reduce the luminance ratios.

5.2 Additional Monitoring of Daylighting Systems

Daylight distribution

A grid of sensors ($E_{wp\ 1\text{-}15}$) will measure more extensively the quantity and distribution of the horizontal illuminance across the width of the room for both sunny and cloudy (overcast) sky conditions (see figure 4).

Change in daylight distribution

Measurements on the walls and the ceiling are essential to record in order to understand how the daylighting system impacts on the daylight penetration and how the diffuse daylight and direct sunlight are distributed throughout the space. Details of the measurements are:

- Vertical illuminance measurements on the walls record the quantity of daylight and reflected sunlight, particularly in the morning and in the afternoon.
- The ceiling is an important secondary component of a daylighting system, since daylight and sunlight can be either directed or reflected by the daylighting system towards the ceiling and reflected from the ceiling into the room. Measurements of incident illuminance on the ceiling will indicate the quantity of daylight being reflected into the room.
- Luminance measurements on the walls and the ceiling show if the amount of reflected daylight and sunlight is within an acceptable range and if these surfaces are not secondary sources of glare. Care should be taken if the luminance values exceed 10.000 - 15.000 cd/m².
- Minimum evaluations on visual comfort and user acceptance in a test room consist of observations taken in both occupied and unoccupied rooms. This includes detection of sunpatches, areas with high luminance and detection of glare sources within the room.

Detection of sun patches, areas of high luminances, glare and colour dispersion

An evaluation through observation should be described in the test report, and photographs of the specific lighting conditions that have been evaluated should be included.

Maintain user acceptance

A user acceptance evaluation should be outlined in the test report to indicate whether the visual comfort and the user acceptance criteria were maintained after applying a daylighting system. The specific lighting conditions that have been evaluated should be documented through photographs.

5.3 Minimum monitoring of Daylight Responsive Artificial Lighting Control Systems

Maintain the design illuminance level

Daylight responsive artificial lighting control systems need to be checked on their ability to control artificial light in response to available daylight, so that the illuminance level on the work plane would not fall short of the illuminance value set in the tuning procedure.

- Measured quantity: E_{wp}

  There are two parameters that show the performance of a daylight responsive artificial lighting control system with respect to the design illuminance level to be maintained:

  1) The (relative) illuminance E_{wp} as a function of time shows the actual time when the design level is not reached (see figure 11).

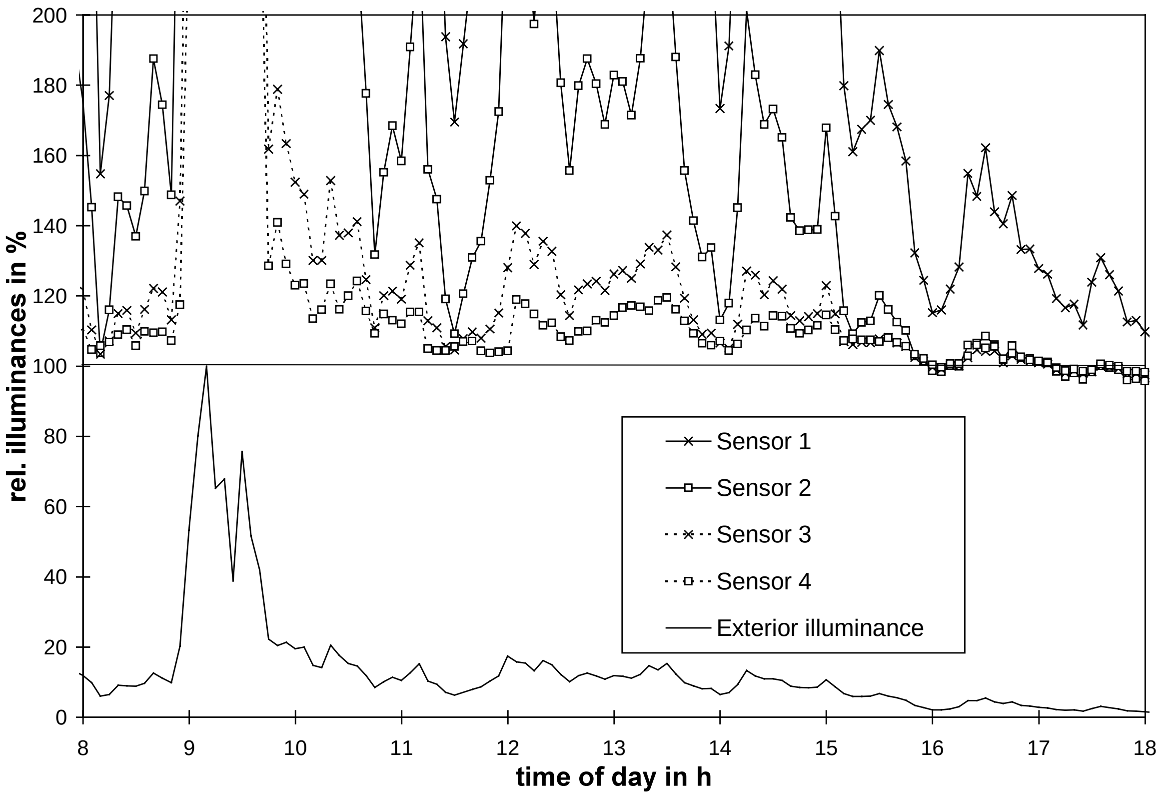


Figure 11: Example of measured illuminance over a test day

2) The frequency of lacking and exceeding the design light level. When a daylight responsive artificial lighting system realises illuminance levels that are lower then the design level, the energy savings will be higher, but the system is not functioning properly. It should maintain at least the design illuminance. Therefore, the frequency of lacking light is a good performance measure (Knoop 1998). An example is given in figure 12.

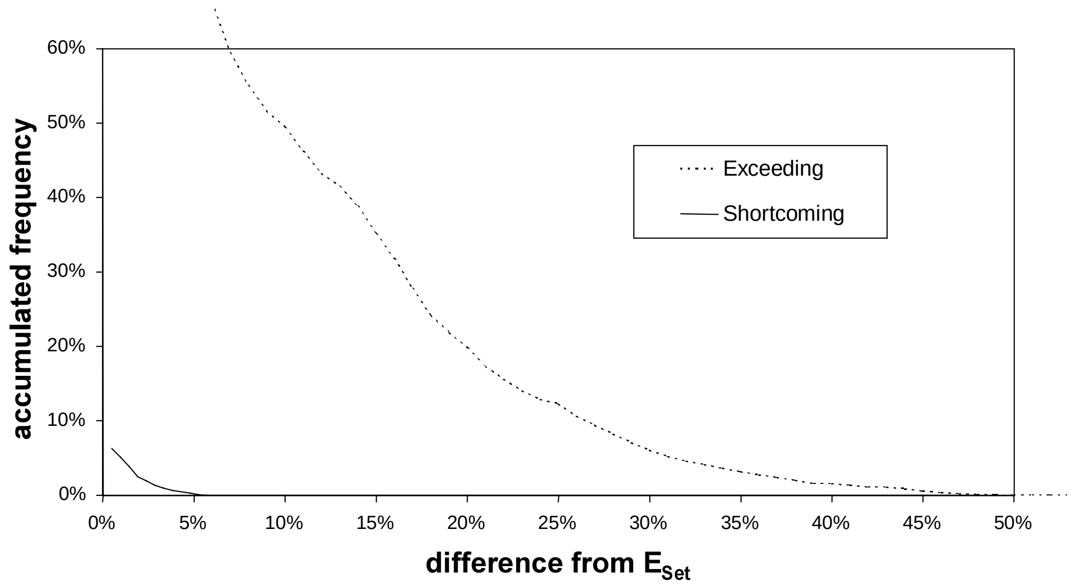


Figure 12: Frequency of the difference between the illuminance level on the work plane and the design illuminance

In the analysis of a daylight responsive artificial lighting control systems, it is important to take into account the number and position of the sensors that are being used. For example, a system A that is monitored with nine sensors (as shown in figure 5) can show a larger deficiency in light exposure then a system B that is monitored with only three sensors in the middle of the room. This does not mean that system A performs worse then system B, although the deficiency in light exposure shown in the graphs would give this impression. System B might have shown a similar performance, or even a worse performance than system A if nine sensors instead of three have been used to monitor the light levels in both cases.

In addition, a separation between the daylight and the artificial lighting contribution can be made (see figure 13 and 14), in order to characterise the exact performance of the control system over the day, in response to the daylight contribution to the room. These graphs can be obtained in two ways as follows:

- Measured quantity: E_{wp}

In the Reference Situation, the illuminance E_{wp} is determined by the daylight contribution and a fixed artificial lighting contribution (the design level). From this two parameters the daylight contribution to the space can be determined:

$$E_{wp} = E_{daylight} + E_{design}$$
$$E_{daylight} = E_{wp} - E_{design}$$

The artificial lighting contribution in the room with the daylighting responsive artificial lighting conditions can be determined using the following equations:

$$E_{wp} = E_{daylight} + E_{art.light}$$
$$E_{art.light} = E_{wp} - E_{daylight}$$

Equation 1

- Measured quantity: dimming level (between 1 and 10 Volt)

  In this case the dimming level is measured, and the Reference Situation can be calculated from measurements obtained right in the test room where the control system is installed. An additional Reference Situation is not needed.

  In the situation with the control system, E_{wp} is determined by the daylight contribution and a variable artificial lighting contribution, which is determined based on the monitored dimming level. The relationship between the dimming level and the illuminance level can be determined as shown in figure 6 from the power consumption and the dimming level. The daylight contribution can then be calculated using the following equations:

$$E_{wp} = E_{daylight} + E_{art.light}$$

$$E_{daylight} = E_{wp} - E_{art.light-calculated}$$

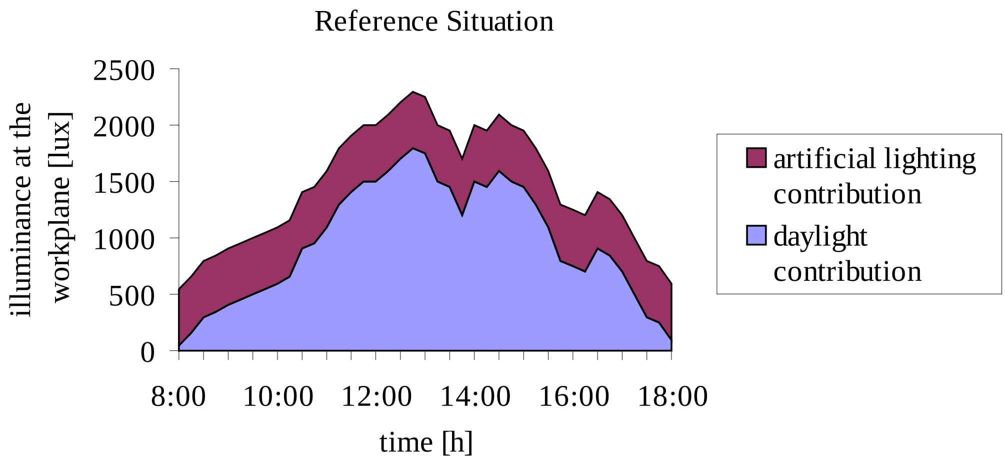


Figure 13: Example of the measured artificial lighting and daylight contribution to the overall illuminance on the work plane in the reference situation

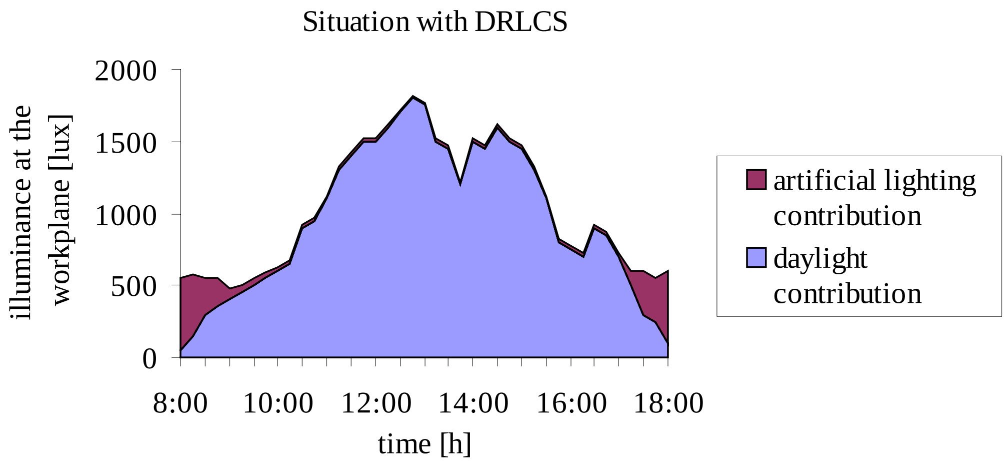


Figure 14: Example of the measured artificial lighting and daylight contribution to the overall illuminance on the work plane in the situation with the control system

Decrease of the electrical energy consumption for artificial lighting due to the use of a daylight responsive artificial lighting control

Energy savings are a direct result of the total number of hours the system has been in use, and the time of the day when the system was used. When comparing a system used from 9 AM until 5 PM with a system used from 5 AM until 10 PM, the latter system will have by far more hours of operation without daylighting and will show a considerable lower percentage of energy savings.

It is difficult to estimate the hours of use of a system when it is manually controlled, since this depends on arbitrary factors such as occupancy patterns and user behaviour. Therefore, a decision has been made to compare the actual power consumption of the daylight responsive lighting control system to the power consumption of the artificial lighting operating fully during working hours, so that the effect of manual switching can be excluded. In this way the most objective evaluation of the system can be made.

- Measured quantity: E_{total}

  Energy savings due to the daylight responsive artificial lighting control may come from:

  1. use of more solar energy for heating in winter
  2. reduction of the artificial lighting consumption through the use of daylighting
  3. reduction of the cooling load, both from avoidance of overheating from the sun through shading and as a result of less energy being dissipated by the artificial lighting

  This monitoring protocol will concentrate on (2), the reduction of the electric energy used by artificial lighting as a direct result of the use of a daylight responsive control system. The artificial lighting design can be over-dimensioned to compensate for maintenance losses and necessary rounding to a whole number of luminaires. As mentioned in chapter 1, the reference situation refers to a 100% output of the artificial lighting. Therefore, over-dimensioning is not taken into consideration, since it does not represent the primary aim of a control system.

The overall savings due to the use of the control system is the total power used by the control system during the monitoring period compared to the power the system would have used without the control system. This can be expressed as a percentage as follows:

$$\%\,\text{Savings} = 100 \cdot \left(1 - \frac{W_{total}}{T_{total} \cdot P_{nominal}}\right)$$

The nominal power ($P_{nominal}$) consumption of a system represents the power consumption calculated taking into account the power used by the lamps as well as the electronics needed to drive the lamps. W_{total} is the electric energy consumption measured during the monitoring period.

The actual energy (P_{actual}) consumption of the system can be obtained through a night-time measurement, when the artificial lighting is not dimmed. The energy savings are as follows:

$$\% \text{ Savings} = 100 \cdot \left(1 - \frac{W_{total}}{T_{total} \cdot P_{actual}} \right)$$

- Measured quantity: dimming level (between 1 Volt and 10 Volt)

  With the previously established relation between the measured voltage and the power consumption of the artificial lighting (P(V)) (see figure 6), the power consumption per time interval, Δt, can be determined. A summation over the whole test period gives the overall power consumption.

$$\% \text{ Savings} = 100 \cdot \left(1 - \frac{\left(\sum_{i=1}^{n} P_i(V) \cdot \Delta t \right)}{T_{total} \cdot P_{actual}} \right)$$

5.4 Additional monitoring of Daylight Responsive Artificial Lighting Control Systems

The user acceptance evaluation obtained by means of a questionnaire should be described in the test report to indicate whether the visual comfort and user acceptance aspects were maintained while applying the daylight responsive lighting control system. The specific lighting conditions that were evaluated and recorded on pictures should be included.

Appendix A: Estimating the impact of obstructions on horizontal external illuminance measurements

by Paul Littlefair, Building Research Establishment

In daylight factor measurements, the external photocell should be completely unobstructed. Sometimes this can be difficult to achieve where there are significant external obstructions but data can be corrected for by using a Waldram Diagram technique (Hopkinson 1966). The attached diagram, for a CIE Overcast Sky, can be used for this purpose. It contains an altitude and azimuth grid on which obstructions can be plotted. To determine these angles, a theodolite, or measurements of the height, width and distance of obstructions, either on site or using plans, can be used. The relative height of obstructions can sometimes be determined by counting bricks, or counting storeys for a tall, far away building. In emergency, if a theodolite is not available, it is possible to sight through a long straight edge, like a meter rule, on a level table. In plotting the obstructions remember that the angular height subtended by a large building will vary along its roofline, because the distance from the observer is different.

Once plotted, the fraction of direct sky light blocked by the obstructions is given by the area A_{obs} occupied by the obstructions on a diagram, divided by the total area of the grid A_{tot}. A correction must be made for light reflected from the obstruction; this can be taken to be 0.9 ρ_{obs} A_{obs} where ρ_{obs} is the obstruction reflectance. For buildings ρ_{obs} = 0.22 is typical, giving 0.2 A_{obs} as the correction. The external global illuminance on a horizontal plane (E_{vg}) need to be multiplied by the following equation to convert it to the equivalent unobstructed value:

$$E_{vg} \cdot \frac{1}{\left(\frac{1 - A_{obs}(1 - 0.9\rho_{obs})}{A_{tot}}\right)}$$

Description of exterior obstructions

Waldram-diagram (see figure A.1) and a fisheye photograph taken from the interior superimposed on a sunpath diagram to represent obstructions should present the description of the exterior obstructions. Measure the obstruction angles and direction and plot the values in a Waldram-diagram. Furthermore, if large trees are positioned outside the test rooms, their position should be marked on both the sunpath diagram and the Waldram-diagram, since their foliage can cause some shading of the windows in the test rooms.

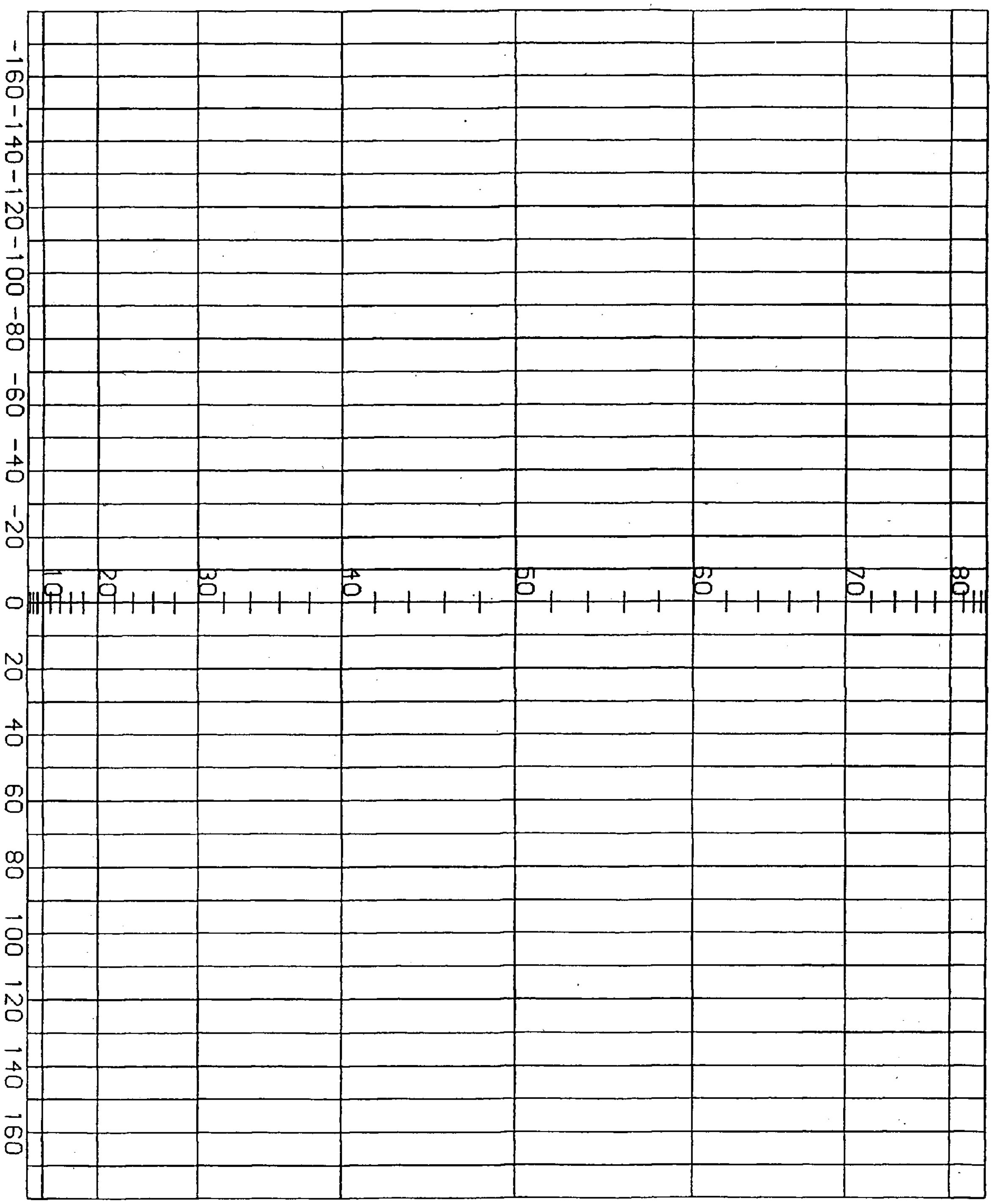


Figure A1 Waldram-diagram

Appendix B: Position of sensors for a minimum number of sensors

Monitoring a ***daylighting system***

The minimum number of interior measurement locations suggested in figure B1 will mainly monitor the illuminance distribution throughout the length of the room. These positions are sufficient and suitable for both traditional window configurations and innovative daylighting systems or solar shading devices attached to windows. For a minimum evaluation of the horizontal illuminance, the sensors should be placed on a symmetrical (centre) line perpendicular to the window at the work plane height (as shown in the descriptive document). Minimum five sensors have to be equally spaced within the room. The sensors located next to the window wall and the rear wall should be located from the walls at a distance equal to half of the distance between the remaining sensors. For example, a room which is 6 m deep will have the sensors positioned at 0.6 m, 1.8 m, 3 m, 4.2 m and 5.4 m (see figure B1).

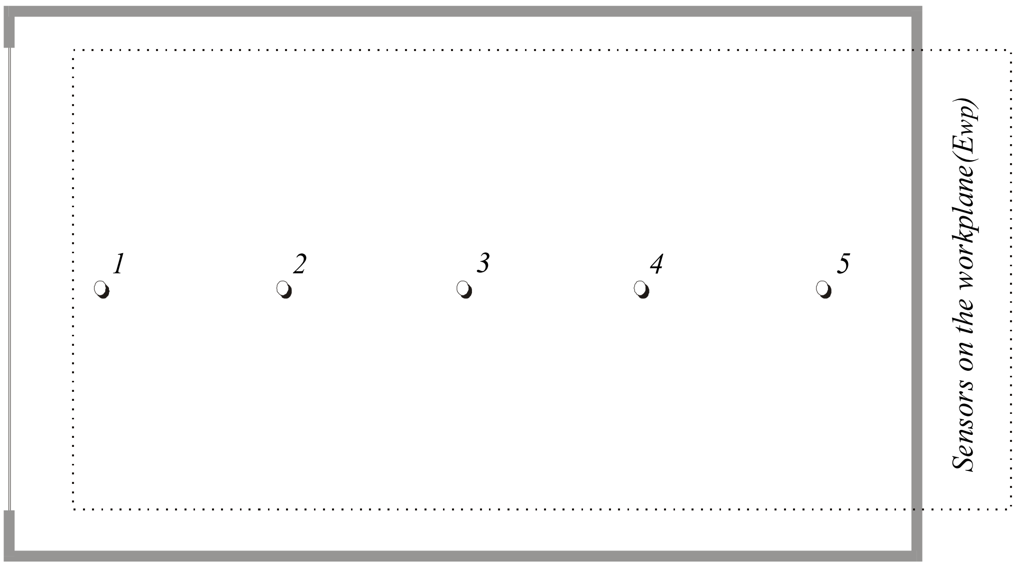


Figure B1 Position of the sensors - daylighting system

Monitoring a ***control system***

The minimum number of interior measurement positions suggested in figure B3 will mainly monitor the design illuminance in three specific lighting areas of a room: the daylight area, the mixed area and the artificial light area. This subdivision of a room is based on the effective window height (see figure B2)

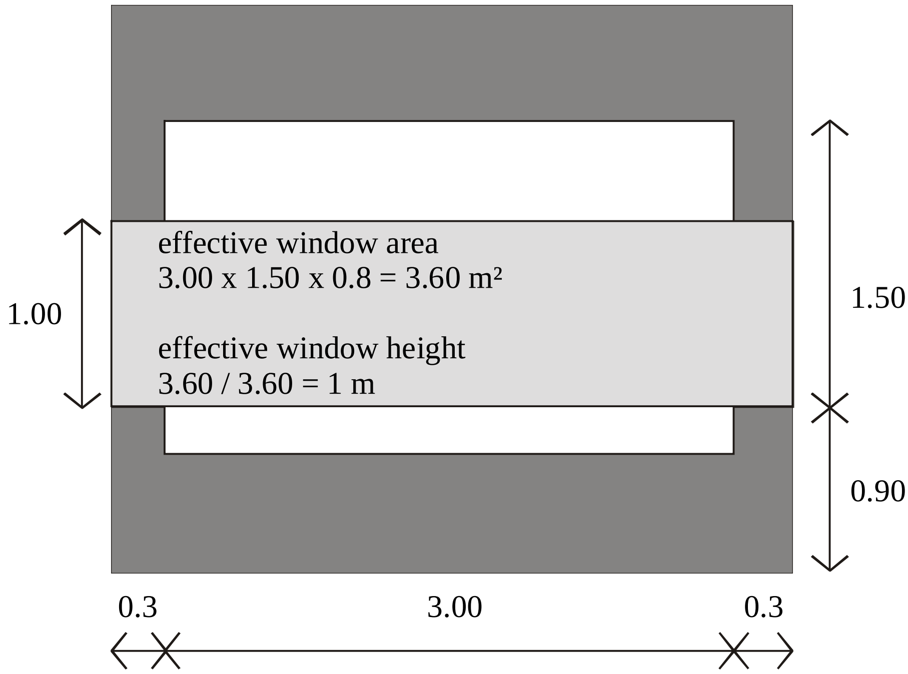


Figure B2 Example of the determination of the effective window area and effective window height

The **effective window area** is the actual glass area above 0.9 m from the floor in the façade multiplied by the transmission of the window pane (e.g. 0.8 for double glazing, as shown in figure B2).

The **effective window height** is the effective window area divided by the width of the façade.

This division is possible if the effective window area is greater than 1/6 of the total façade area above 0.9 m. In the case of two or more windows in one façade the effective window height will be calculated from the **total** effective window area divided by the width of the façade.

A room can be subdivided in three areas (see figure B3):

Daylight area

The daylight area in a room is the area with a high daylight level. This area starts at the façade and has a depth of approximately two times the effective window height. In general, this area will be sufficiently illuminated by daylight to perform a normal task.

Mixed light area

The mixed light area is the area with a medium daylight level. This area will need some supplementary artificial lighting to accomplish a satisfactory light level throughout the day. The area starts at the inner border of the daylight area and has a depth of approximately 1.5 times the effective window height.

Artificial light area

The artificial light area is the area with a low or no daylight level. This area will be illuminated by artificial lighting, the daylight contribution being too low. This area will be the remaining part of the room towards the rear wall.

Based on the three types of light area described above, the three monitoring sensors will be placed in the room as follows:

- one sensor in the middle of the daylight area (at 1.0 times the effective window height of the reference case). This sensor is labelled wp1 in figure B3.
- one sensor in the middle of the mixed light area (at 2.75 times the effective window height). This sensor is labelled wp2 in figure B3.
- one sensor in the middle of the artificial light area. This sensor is labelled wp3. If the depth of the room is less than 3.5 times the effective window height, this area does not exist. In this case the third sensor should be positioned at the borderline between the daylight and mixed light areas. The sensor will be labelled wp2 and the sensor in the middle of the mixed light area will be labelled wp3 in figure B3.

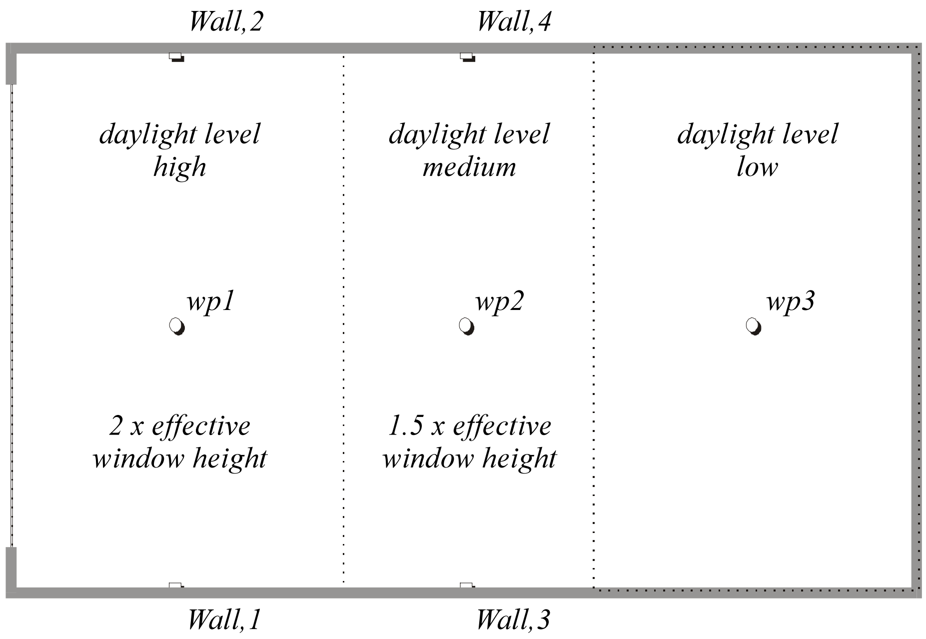


Figure B3 Position of the sensors - Monitoring of a control system

More windows in one façade

In the case of two or more windows in one façade the sensors should be positioned at the work plane height on a center line in the middle of the area where the windows are positioned. .

Appendix C: Assessment of glare

by Maurice Aizlewood, Building Research Establishment

The potential to control daylight glare is an important feature of the daylighting systems under test. There are a number of glare indexes that have been developed. The monitoring protocol has been developed to provide the necessary data for calculation of the Daylight Glare Index (DGI)(1). The DGI is given by the formula:

$$DGI = 10 \log_{10} 0.478 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega^{0.8}}{L_b + 0.07 \cdot \omega_s^{0.5} \cdot L_w}$$

L_s is the average luminance of each glare source in the field of view [cd/m2]
L_b is the average luminance of the background excluding the glare source [cd/m2]
L_w is the average luminance of the window [cd/m^2]
ω_s is the solid angle of the source seen from the point of observation [sr]
Ω is the solid angle subtended by the source, modified for the position of the light source with respect to the field of view and Guth's position index P [sr].
n is the number of glare sources

Rather than attempting to make a difficult series of frequent spot luminance measurements in the test rooms, the protocol calls for continuous measurement of shielded and unshielded vertical illuminances from which L_s, L_b and L_w can be derived[1]. Example vertical sensors are shown in Figure C1. One sensor is unshielded and measures the vertical illuminance at that point in the room. A cone of black material shields the other sensor such that it only receives direct light from the window. The glare source luminance L_s is determined from:

$$L_s = \frac{E_{shielded}}{\pi \cdot \phi}$$

where ϕ is the configuration factor of the glare source with respect to the measurement point (see appendix D).

The background luminance L_b excludes the area of the glare source and is given by:

$$L_b = \frac{E_{Unshielded} - E_{Shielded}}{\pi \cdot (1 - \phi)}$$

The value L_w is the average luminance of the window. If the shielding cone is shaped such that the shielded sensor sees the whole window but nothing else, then L_w is the same as L_s. This is the preferred configuration, and results in a "cone" with an irregular pyramidal shape. Alternatively, it is easier to build a simple cone or cylinder. In this case the shielded

[1] The authors would like to add that it has not been proved yet if this experiment is reliable in situations with daylighting systems (for more information see Velds 2000).

sensor sees only part of the window. Care should be taken that the sensor sees an average portion of the window such that L_w can be treated as L_s.

ω_s is the solid angle subtended by the glare source (window) to the point of observation. It can be calculated using the following equation:

$$\omega_s = \frac{A \cdot cos\,\theta \cdot cos\,\varphi}{d^2}$$

A is the window area [m^2]
d is the distance from the viewpoint to the centre of the window area [m]
θ,φ are the angles between the line of sight and the centre of the window area

Figure C1 Example of the shielded and unshielded illuminance sensors used to calculate the DGI

Ω is slightly more difficult to calculate. It is the solid angle subtended by the window, modified by the position index of the window, P. The basis of this modification is that the original data collected by Hopkinson (2), was for a glare source 10^o above the line of sight. A glare source directly in the line of sight would be significantly more glaring, while at the periphery of vision it would be notably less glaring. A table of values for P is given in Figure C3). Ω is calculated using:

$$\Omega = \sum P_i \cdot d\omega_s$$

$d\omega_s$ the solid angles of elements of the window and
P_i the position indexes of those elements.

Calculating Ω with a large number of elements may generate a small increase in accuracy. The DGI formula is expressed as a sum of the individual glare sources in the field of view. One of the problems with the DGI is that if you divide a large glare source into a number of smaller sources and then sum them up at the end you would not get the same result as if you treated the source as one large element (3). This lack of mathematical consistency exists because the DGI is an experimental fit to data. For the purposes of this protocol, the summation in the DGI formula can be ignored and the daylighting systems can be treated as one large source.

The DGI (and this method of calculating it) only considers average daylight glare. It does not take into account direct sunlight striking an occupant. Nor does it consider small areas of high brightness within the overall window area such as the bright vertical lines that can be produced by prismatic systems in direct sunlight (4). For this reason, spot measurements and photographs should be used to record additional glare phenomena.

TABLE 12.7

POSITION FACTOR p (FOR USE WITH FIGURE 12.7)

	Horizontal angle ($\phi = \tan^{-1}$ L/R)																		
Vertical displacement (V/R)	0°	6°	11°	17°	22°	27°	31°	35°	39°	42°	45°	50°	54°	58°	61°	63°	68°	72°	*Vertical angle* ($\theta = \tan^{-1}$ V/R)
1·9	—	—	—	—	—	—	—	—	—	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	62°
1·8	—	—	—	—	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	0·02	61°
1·6	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·03	58°
1·4	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·04	0·03	0·03	54°
1·2	0·05	0·05	0·06	0·06	0·06	0·06	0·06	0·06	0·06	0·06	0·06	0·05	0·05	0·05	0·05	0·04	0·04	0·04	50°
1·0	0·08	0·09	0·09	0·10	0·10	0·10	0·10	0·09	0·09	0·09	0·08	0·08	0·07	0·06	0·06	0·06	0·05	0·05	45°
0·9	0·11	0·11	0·12	0·13	0·13	0·12	0·12	0·12	0·12	0·11	0·10	0·09	0·08	0·07	0·07	0·06	0·06	0·05	42°
0·8	0·14	0·15	0·16	0·16	0·16	0·16	0·15	0·15	0·14	0·13	0·12	0·11	0·09	0·08	0·08	0·07	0·06	0·06	39°
0·7	0·19	0·20	0·22	0·21	0·21	0·21	0·20	0·18	0·17	0·16	0·14	0·12	0·11	0·10	0·09	0·08	0·07	0·07	35°
0·6	0·25	0·27	0·30	0·29	0·28	0·26	0·24	0·22	0·21	0·19	0·18	0·15	0·13	0·11	0·10	0·10	0·09	0·08	31°
0·5	0·35	0·37	0·39	0·38	0·36	0·34	0·31	0·28	0·25	0·23	0·21	0·18	0·15	0·14	0·12	0·11	0·10	0·09	27°
0·4	0·48	0·53	0·53	0·51	0·49	0·44	0·39	0·35	0·31	0·28	0·25	0·21	0·18	0·16	0·14	0·13	0·11	0·10	22°
0·3	0·67	0·73	0·73	0·69	0·64	0·57	0·49	0·44	0·38	0·34	0·31	0·25	0·21	0·19	0·16	0·15	0·13	0·12	17°
0·2	0·95	1·02	0·98	0·88	0·80	0·72	0·63	0·57	0·49	0·42	0·37	0·30	0·25	0·22	0·19	0·17	0·15	0·14	11°
0·1	1·30	1·36	1·24	1·12	1·01	0·88	0·79	0·68	0·62	0·53	0·46	0·37	0·31	0·26	0·23	0·20	0·17	0·16	6°
0	1·87	1·73	1·56	1·36	1·20	1·06	0·93	0·80	0·72	0·64	0·57	0·46	0·38	0·33	0·28	0·25	0·20	0·19	0°
	0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·2	1·4	1·6	1·8	2·0	2·5	3·0	
	Lateral displacement (L/R)																		

V = vertical distance from horizontal line of vision
L = lateral distance from horizontal line of vision
R = horizontal distance from eye of observer

Figure C2 Table of position index

Measurement advice

The DGI is supposed to be "substantially independent" of the measuring position. Thus, the positioning of the vertical sensors is not critical. A distance from the window of 3 m or more is recommended. The position should be chosen such that the vertical cells do not directly shade any horizontal cells. The DGI is a daylight glare index, not a sunlight glare index. At any time that direct sunlight falls on the vertical cells, the formula can become unreliable. Cells should be far enough from the window relative to the window head height and solar elevation so that direct sunlight does not strike the cells too often. If the shielding cone has been chosen to align with the corners of the window, then care should be taken to line up the shielded sensor correctly. One method is for an observer to look from the corners of the window towards the shielded sensor and get an assistant to adjust the shielding and sensor position until the whole sensor head is only just visible from each position. Alternatively, if the shielding construction allows it, a small light source within the cone can be used to align the sensor with the window corners at night.

Appendix D: Configuration factor for element parallel to rectangle Φ_I

The configuration factor Φ_i of the examined part of the window from the viewpoint of the observer can be found for instance by assuming the area of where the measurements are recorded as a small area ΔF_1 parallel to the examined rectangular part of the window area F_a. The small area ΔF_1 lies on a line perpendicular to one corner of the examined rectangular part F_a. In order to adjust to different windows and reference location combinations that do not match the requirements that ΔF_1 lies on line perpendicular to one corner of F_a, the configuration factor Φ_i can be determined by adding and/or subtracting the Φ_i of two or more hypothetical rectangles.

The configuration factor Φ_i can be estimated by the following equation or by the graph in figure D.1, derived from [ETSU 1993].

Input Parameter X and Y where

$X = \frac{a}{c}$ and $Y = \frac{b}{c}$ as in diagram

Equation $$\Phi_i = \frac{A \arctan B + C \arctan D}{2\pi}$$

where $A = \frac{X}{\sqrt{1+X^2}}$, $B = \frac{Y}{\sqrt{1+X^2}}$, $C = \frac{Y}{\sqrt{1+Y^2}}$, $D = \frac{X}{\sqrt{1+Y^2}}$

Note Angles are expressed in radians

Reference:

Siegel R, Howell J R, *Thermal Radiation Heat Transfer*, McGraw Hill, 1972

ETSU, *Daylighting Algorithms*, Prepared by Tregenza P, Sharples S, Renewable Energy Research and Development Programme, Energy Technology Support Unit (ETSU), 1993

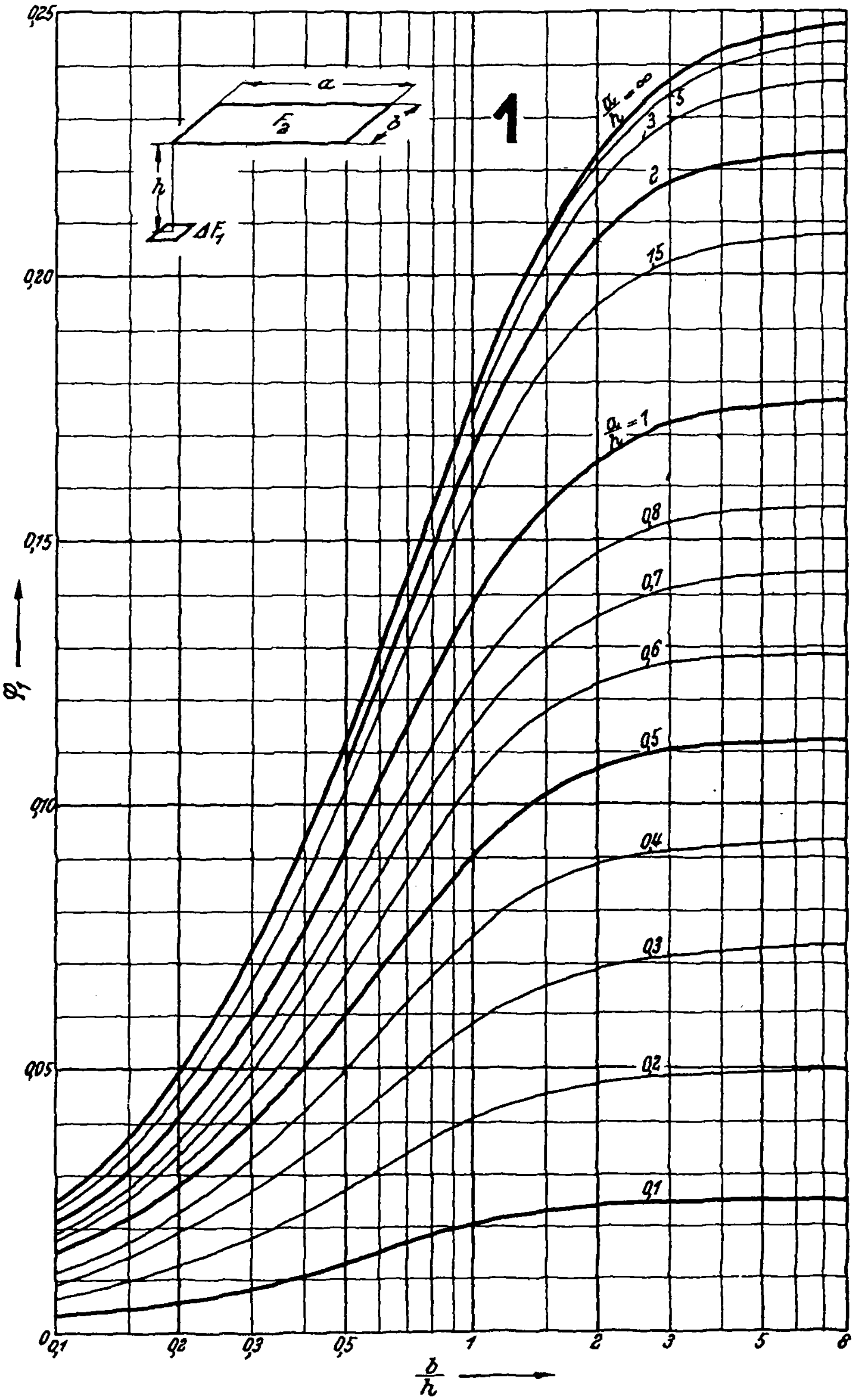


Figure D.1: Configuration factor

Appendix E: Assessment of users' evaluation of lighting conditions in test rooms

by Kjeld Johnsen, Jens Christoffersen, Erwin Petersen, Staffan Hygge, Hans Allan Löfberg,

Introduction

This document describes procedures and questionnaires that can be used for the assessment of users' opinions on daylighting systems and lighting control systems installed in full scale test rooms. A number of test persons are asked about their impression, opinion and experience of the room during a half-hour stay in a test room where they are asked to conduct certain office-like tasks.

This survey is assumed to complement measurements of the rooms' physical conditions, as well as the energy performance of the installed systems as described in the Monitoring Protocol.

Daylighting systems will normally be more technological and more expensive than traditional windows. An important part of the test is therefore based on the comparison between the system in question with a 'neutral' reference system installed in a room identical to the test room. The question will then be if from the users' view-point the daylighting system can improve the comfort or working conditions in comparison to a more traditional solution.

The questionnaire is designed to cover single-, two-, or three-person offices or similar rooms with window(s) in at least one façade. In order to use it for rooms daylit solely by rooflights, some of the questions need to be changed.

Conditions for Test Rooms

The questionnaire implies that the test rooms are furnished and decorated in such a way that the test persons will get a feeling of being in a normal ordinary office.

The finishing of the walls and ceiling should be light coloured without any glossy surfaces. The reflectances should be within the following ranges:

Ceiling:	0.7-0.85
Walls:	0.6-0.75
Floor:	0.5-0.65

Depending on the size, the rooms should be equipped with 1 to 3 workplaces, each having a desk, an office chair, and a computer (pc). The side walls should be partly covered with shelves or bookcases with average reflectances of 0.5-0.6, and one or two neutral posters on the walls.

Selection of test persons

The test persons are selected from among people that are used to do office-like work. They must, for instance, have some experience in working with computers, and should have no problems in reading a normal text page within a few minutes. For economical reasons, the test persons will often be found among students. In any case, it is important that the test persons make a relatively homogenous group of people, i.e. same age - under 45, and have approximately the same level of education. This means that even before the testing, some potential test persons will be ’disqualified’, so that the personal questions in the questionnaire can be limited to a minimum.

When the test persons come into the test rooms for the first time, the only knowledge they may have about the look of the test rooms should be based on the information given by the staff being responsible for the testing. In order to reduce biases caused by the test persons having or not having experience with the test rooms from previous visits, it is recommended that all test persons be given a thorough introduction to the tests, including a brief walk-through of the test rooms before the tests begin.

The sequence of the tests

The main experiment is to assess the test persons’ opinion about the system to be tested (daylighting or lighting control system) in comparison with a more traditional solution. Each person should go ’directly’ from the test room to the reference room, - or for 50% of the persons visa versa -, with as short a break as practically possible. This is in order to obtain (as far as possible) the same sky condition, and a fresh memory/impression from the first test. It is of course of extreme importance that the sky condition is almost the same during the whole test.

If both the test room and the reference room are each arranged with two workplaces (called workplace 1 and workplace 2), there are two comparisons of interest: a) the comparison between workplaces 2 of the two different rooms and b) the comparison between workplace 1 and workplace 2 in each of the two rooms. Again, since comparison a) is of greater interest than b), it is important that each test person switches directly between the two workplaces 2 of the two rooms. If the sky condition is stable (consistently clear sky or consistently overcast), it might be possible for each test person to undergo all four tests on the same day. If the sky condition is unstable and changes after the first tests, comparison between workplaces 2 of the two rooms may still be possible, while comparison between workplace 1 and workplace 2 in each of the rooms will probably be meaningless.

For further guidance on the best way to organise series of tests in test rooms, please consult the document: *Post-occupancy evaluation of daylight in buildings* by Staffan Hygge, Hans Allan Löfberg.

Timing of tasks during the Test

The duration of a full one person test in the test rooms and in the reference room is assumed to take about 60 minutes, according to the following plan:

Time, minutes	Activity Room 1
-5-0	Introduction to test
0	Test begins
1-2	Read introduction
3-4	Part 1, personal, room 1
5-7	Part 2, about room, room 1
8-28	Part 3, conduct tasks, Fill in questionnaire, room 1

Time, minutes	Activity Room 2
30-35	Get accustomed to room 2
35-37	Part 2, about room, room 2
37-53	Part 3, conduct tasks, Fill in questionnaire, room 2
55-60	Comparison of rooms

Questionnaire on lighting in working spaces

These lines should already have been filled in by the staff

Person ID:	
Date:	
Time:	

Introduction

This questionnaire is used for the assessment of people's opinions on daylighting systems, artificial lighting systems and lighting control systems installed in test rooms. The survey complements measurements of the physical conditions, as well as the energy performance of the installed systems.

Please complete the questionnaire as you are instructed, and be frank and honest in your answers. Do not hesitate to consult the staff if you have any questions or doubts. Your personal opinion is of great interest to us, and will remain unrevealed to others than the scientific personnel taking care of the statistics.

Before filling in the Questionnaire

Before starting, we want you to familiarise yourself with the room. Just sit back, look around and feel relaxed for a couple of minutes.

The questionnaire is simple, so take your time when asked about your opinion regarding what you experience.

The questionnaire has 3 parts:

Part 1) questions about yourself

Part 2) questions about your general impression of the room

Part 3) questions about the room as a workplace

You have been instructed to perform certain tasks during your stay in the room. These will take place in Part 3.

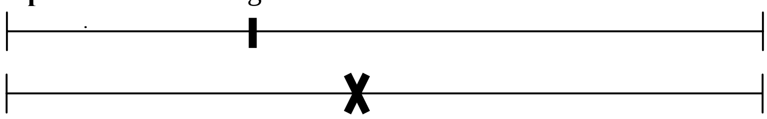
After you have filled in the questionnaire (the first time), you will be asked to move to the other desk in the room and answer the questions in part 2 and 3 again (as seen from the new position).

Finally, after your have given your opinion about the two workplaces in this room, you will be asked to follow the same procedure in the other room, which has a different window or daylighting system.

When answering questions including scales, please indicate your opinion by setting one mark on each of the lines

Example:

right



wrong

1. Questions about yourself

1.1 Do you normally wear glasses or contact lenses when doing office-like work?

☐ Yes

☐ No

1.2 Are you right handed or left handed?

☐ Right handed

☐ Left handed

1.3 Gender

☐ Female

☐ Male

1.4 Age

☐ Years

1.5 Do you consider yourself as sensitive to bright light?

	Not at all	Very much
Sensitive	|———————————————|	

Room 1, Workplace 1

2. Questions about your impression of the light and the room

2.1 In general, how do you rate the *light level* in the room?

Low — High

The overall light level of the room

The level on the desk

2.2 From your present location, do you experience any unpleasant gloomy (dark) areas in the room?

Not at all — Very Much

Gloomy areas

2.3 From your present location, do you experience any unpleasant bright areas in the room?

Not at all — Very Much

Bright areas

2.4 When you are looking out of the window(s), is the view restricted by any of the following elements?

Low — High

By the window size

By the daylighting system

By the shading devices/curtains

2.5 When looking up from the desk, do you feel any glare?

Not at all — Very much

When looking straight forward

When looking towards the window

2.6 What is your general impression of the *room*? [2]

Pleasant		Unpleasant
Interesting		Monotonous
Like		Dislike
Light		Dark
Evenly lit		Unevenly lit
Spacious		Cramped
Bright		Dim
Calm		Noisy
Informal		Formal

3. Questions about the light and the room for a workplace

Now, we want you to do a little work for us. Before answering any of the following questions, we kindly ask you to read the papers marked A1-1 and B1-1, and then retype the text on the computer screen. When reading the papers, please leave them flat on the desk. We will be interested in knowing if you experience any problems with reflections or lack of contrast in some of these working materials. In the papers A and B there are some errors. Please mark those you find.

Tick the following boxes, as you go along:

☐ **Now, I have read the text of the paper marked A1-1.**

☐ **Now, I have read the text of the paper marked B1-1.**

☐ **Now, I have typed in the text on the screen.**

Now, to the questions:

3.1 Did you feel disturbing reflections in any of your working material ?

	Not at all	Very much
In paper A, on your desk		
In paper A, on your desk		
In the VDU screen		

[2] This list can be extended.

3.2 Did you experience difficulties concerning the visibility of the text in any of your working material ?

	Not at all	Very much
Paper A, on your desk		
Paper A, on your desk		
The VDU screen		

3.3 During your stay in this room, have you been uncomfortable with any of the following indoor climate conditions?

	Not at all	Very much
High temperature		
Low temperature		
Draft		
Odour		
Dust		
Noise		

3.4 During your stay in this room, did you experience any need to adjust the solar shading?

☐ Yes

☐ No

3.5 If you should work for a longer time under conditions similar to the ones experienced during your stay in this room, would you turn on any of the electrical light?

	Yes	May be	No
The desk light	☐	☐	☐
The general lighting in the ceiling	☐	☐	☐

Room 2, Workplace 1

4. Questions about your impression of the room - workplace 1

Same questionnaire as part 2, but now in Room 2.

5. Questions about the room as a workplace - workplace 1

Same questionnaire as part 3, but with different sheets of papers, now marked A2-1 and B2-1, respectively, and with a new text on the computer screen.

6. Comparison of rooms - workplace 1

You have now given your opinion of the two rooms. Now we want you to make a more direct comparison between the two rooms. We kindly ask you to walk freely in between the two rooms and compare workplace 1 of both of the rooms. Sit down, and see how you feel about the working place. Is there anything you particularly like or dislike?

We want you to take your time, when answering the following questions.

6.1 Which room would you prefer to work in, when you compare with respect to:

	Prefer Room 1	Prefer Room 2	I am not sure
The general impression of the room	☐	☐	☐
The view out through the window	☐	☐	☐
The light distribution in the room	☐	☐	☐
..??	☐	☐	☐

6.2 Do you experience any other difference between the two rooms ?

☐ Yes

☐ No

If yes, please indicate what:

____

____

Thank you very much for your time and co-operation!

Room 1, Workplace 2

Comment: *This part of the test should probably be conducted on a different day, or at least with a pause (1 hour) after the first test. The comparison of one test person's evaluation of workplace 1 and workplace 2 of the same room will of course be weak if the sky conditions are not similar for the two tests, but there will still be a lot of useful information on how the person judges that particular room.*

7. Questions about your impression of the room - workplace 2

Same questionnaire as part 2, but now seen from workplace 2.

8. Questions about the room as a workplace - workplace 2

Same questionnaire as part 3, but with different sheets of papers, now marked A1-2, B1-2, respectively, and a different computer task.

Room 2, Workplace 2

9. Questions about your impression of the room - workplace 2

Same questionnaire as part 2, but now seen from workplace 2.

10. Questions about the room as a workplace - workplace 2

Same questionnaire as part 3, but with different sheets of papers, now marked A2-2, B2-2, respectively, and a different computer task.

Appendix F: Reflectance measurements

by Maurice Aizlewood, Building Research Establishment and Jens Christoffersen, Danish Building Research Institute

Reliable reflectance readings can be difficult to produce. It is therefore important to find the most suitable conditions in which readings can be taken or to reduce the errors if conditions are unsuitable. The reflectance readings should be taken in the laboratory lit only by diffuse natural lighting. The reflectance measurement methods described apply only to matt diffuse surfaces. Reflectance values of significant interior surfaces should be superimposed onto a fish-eye photograph of the interior.

Measurements of the sample should commence once the light levels are stable. To take measurements a luminance meter and an illuminance meter are needed. Both meters should be recently calibrated. The basic set of measurements is:

Method 1: Illuminance - luminance

Place the illuminance meter as close to the point of measurements as possible, without casting any shadows over the point of measurement. Move directly above the sample and aim the luminance meter down at 90° to the sample. Inevitably this will produce some shadows over the sample but in a diffusely lit environment the illumination of the sample will remain substantially uniform. Care should be taken to stand in a similar position for all readings. If possible the luminance meter could be mounted on a tripod and this position held. Focus the luminance meter to the correct distance. When both meters are set up take the readings simultaneously, this is so that the conditions cannot change between the two readings. The following equation can be used to calculate the reflectance from the two readings:

$$\rho(R) = \frac{L \cdot \pi}{E}$$

ρ (R) is the reflectance

L is the luminance [cd/m2]

E is the illuminance [lux]

Method 2: Luminance - luminance

This method involves using a sample whose reflectance is known and another that has an unknown reflectance. The sample whose reflectance is known can be a matt white disc with an accurately known reflection factor. Use the luminance meter (as in method 1) to record values for both the known and the unknown samples (cautiousness should be accounted for by not moving the meter between readings and also not to shadow the sample). The reflectance value of the unknown sample can be determined by:

$$\rho_{unknown} = \frac{L_{unknown}}{L_{known}} \cdot \rho_{known}$$

$\rho_{unknown}$ is the reflection value of the examined surface

ρ_{known} is the reflection value of the known reference surface

$L_{unknown}$ is the luminance of the examined surface [cd/m2]

L_{known} is the luminance of the known reference surface [cd/m2]

Caution should be taken when measuring the reflectance of strongly coloured surfaces since it depends heavily on the spectral distribution of the illuminant and on the V(λ) response of the measuring instrument. The methods discussed give no spectral information, and other techniques may be necessary if strong colours are present. Polished surfaces must be measured with care, as a mirror reflection can distort the results completely. It is suggested that if specular effects are significant, another technique or a gonioreflectometer should be used.

Appendix G: Glazing transmittance measurements

The glazing transmittance should be measured only under an overcast sky. The two methods proposed cover both the hemispherical and normal transmittance of diffuse daylight and should commence once the exterior light levels are fairly stable and the sky is completely overcast. To take the measurements both a luminance meter and an illuminance meter are needed. The two basic methods are:

Method 1: Hemispherical transmittance ($\tau_{diffuse}$)

Place the illuminance meter on the outside glass pane and take the reading. As quickly as possible move the illuminance meter inside approximately 1 cm from the internal glass pane and take the final reading [Berrutto 1995]. Repeat the measurements several times. The following equation can be used to calculate the hemispherical transmittance ($\tau_{diffuse}$) from the two readings:

$$\tau_{diffuse} = \frac{E_{interior}}{E_{exterior}}$$

Another possibility is to take simultaneous readings with an exterior vertical sky illuminance sensor before it is screened from ground-reflected light and an interior sensor as described above. Care should be taken when using this method, since the window surroundings and exterior obstructions can influence the readings.

Method 2: Normal transmittance ($\tau_{\perp}$)

Point the luminance meter perpendicular (acceptable range ± 30°) to the glass pane and take the luminance reading of an opposite patch of the sky or a diffuse part of a building façade (avoid trees) [Berrutto 1995]. It is essential that the luminance value of the reading be fairly high to reduce the influence of the light reflected from the inner glass pane. As quickly as possible open the window and take the final luminance reading at the exact same point. Repeat the measurements several times. Care should be taken to stand in a similar position for all readings. If possible, to hold this position, the luminance meter could be mounted on a tripod. The normal glazing transmittance value ($\tau_{\perp}$) can be determined using the following equation:

$$\tau_{\perp} = \frac{L_{with\ glazing}}{L_{without\ glazing}}$$

If the proposed methods for measuring the glazing transmittance are not practical to carry out due to difficulties in opening the windows or making the exterior measurements, it will be necessary to rely on the manufacturers' specifications, which is not desirable.

Appendix H: Description of the monitoring

Changes before the monitoring started (in comparison to the situation described in the descriptive document):

……………………………………………………………………………………………..
……………………………………………………………………………………………..

Type of monitoring:

- ❑ Short-term monitoring (dates: ....)
- ❑ Long-term monitoring (from .... to ....)

- ❑ Unoccupied test rooms
- ❑ Occupied test rooms

Level of monitoring:

Daylighting system

- ❑ Realise a higher illuminance level on the work plane
- ❑ Realise a higher uniformity on the work plane
- ❑ Reflect direct sunlight
- ❑ Increase the surrounding luminances (walls)
- ❑ Increase the surrounding luminances (ceiling)
- ❑ Maintain user acceptance

Daylight responsive artificial lighting control system

- ❑ Maintain the design illuminance
- ❑ Decrease the electrical energy consumption for artificial lighting
- ❑ Maintain user acceptance

Weather conditions:

Date	Weather condition

Pictures made:

No.	Date - Time

Changes after the monitoring took place:

……………………………………………………………………………………………..
……………………………………………………………………………………………..